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Terzaghi Oration 2005

Associating with advancing insight

S'allier les notions accroissantes

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ABSTRACT
This Terzaghi Oration addresses advancing insight in geotechnics with a focus on the interaction of soil and water. It considers the societal position and the innovation potential of the geotechnical profession with special attention to aspects of knowledge and communication and makes suggestions as to how the profession could benefit from expertise and experience, using modern concepts.

RÉSUMÉ
Ce discours Terzaghi sera consacré aux progrès de notre état de connaissance en géotechnique, particulièrement celui qui concerne l'interaction sol-eau. On y évoquera la position des géotechniciens dans la société, par rapport notamment aux problèmes de l'expertise et de la communication; sur base des concepts actuels, on proposera quelques réflections sur la façon de laquelle la profession faire ses avantages de ses acquis et son expertise.

WHAT ABOUT AND WHY

Modern society does not accept that issues, which are recognized for quite some time, are not being understood. This is becoming a real problem in geotechnics, since uncertainty here is a well-recognized characteristic, unfortunately not always managed in systematic way like in other technical fields. In concrete the uncertainty is less than 10%, in steel less than 5%, but in geotechnics usually more than 50%. Wentink (2000), an experienced contractor and consultant and acquainted with geotechnical specialists, stated: "Without exception, if you work in the construction sector, in any function, you will be confronted with the aspect soil. Every project seems to get a calamity, small or large, related to soil. I thought that after such an event the soil mechanics advisor was wrong, but now I know that every advisor could be right. The difference is the individual risk perception related to the intrinsic uncertainty in soils."

Uncertainty in geotechnics leads often to remarkably high risk and cost (Littlejohn, 1991), and extra vulnerability in areas prone to hazards. Following Littlejohn, we clearly need to explain better the intrinsic uncertainty in geotechnics, to the outside world.

Handling soil-related uncertainties, using the benefits of micro-geomechanics, biotechnology and the Internet, is seen as a new challenge that may improve the situation of the profession significantly. In chapter 1 various examples illustrate aspects of geotechnical uncertainties and limitations and their background. In chapter 2 the characteristics of knowledge are discussed. After capital and labor knowledge is the third production factor. Knowledge can be considered as the power to transform facts into insight, or to formulate actions to reach a goal, or the power to project an object of thought into an existing structure (Newell, 1981). In geotechnics, risk management related to uncertainties could be handled with our expertise and experience in a different way. The issue of knowledge management and ICT is discussed, considering their impact on improvement in content and context. Chapter 3 focuses on communication, i.e. knowledge transfer, in particular on different types of communication. Communicating outside our technical world is becoming essential, specifically to inform others of soil-related uncertainties and how to address them. Chapter 4 describes the process of contextualization, and presents a new paradigm in which geotechnicians should find their place. What is happening already and what is required to be changed? The readiness to invest in knowledge is nowadays about actuality and not about scientific truth. We will look at an example of the current development of an integral approach to a research agenda for the construction sector in Europe, in the context of a knowledge-driven economy. Finally, in Chapter 5 I give some examples of promising innovations, such as a concept for collective brains in geotechnics, a risk-sharing contract model, micro-technology for organic soils, working with bio- and nano-technology, multi-scaling, and a theoretical model for the consolidation of reed peat.

Article 14A.2(i) of the regulations of the International Society of Soil Mechanics and Geotechnical Engineering states that the Terzaghi Oration is delivered as a tribute to Professor Karl Terzaghi, first President of the International Society. The Terzaghi Oration should preferably cover case histories, derived from professional activities and explore the dynamic interaction between consulting work, teaching, research and publication. It should exemplify Prof. Terzaghi's intellectual approach to engineering and geology and to the observational method both for improving design and for the advancement of knowledge.

In this lecture I have tried to return to the fundamentals of geotechnics, into lessons learned or to be learned from the past, into cooperation with other disciplines, and into the position and role of the geotechnical profession, emphasizing the potential impact of knowledge in its context and ways of communication. Globalization and ICT-networking are new drivers that change our approach, but basic research as it started with Terzaghi in the 1920s is still needed, since geotechnics is a rather empirical profession – providing many opportunities and challenges.

1 ADVANCING INSIGHT

Illustrative examples of how insight develops in soil mechanics with a focus on the role of water in soils and the lessons learned or to be learned.

1.1 *Geotechnics, triggered by failure*

The year 1918 was a remarkable year. The so-called Spanish flu, probably caused by a recombinant pig virus from China, made more than 500 million people ill worldwide with 20 to 40 million deaths, in just one year. World-war battles in stagnant trench-warfare under heavy bombardment, machine-guns and chemical weapons took a toll of hundreds of thousands of soldiers, in particular around Ieper in Belgium. In a civil war raging in Russia the last Tsar Nicolas II and his family were murdered. In Constantinople, as the German army retreated, Karl Terzaghi was working at Roberts College. It was the moment of discovering the fundamentals of sand and clay behavior by developing testing equipment, performing experiments and designing the equations that govern observed behavior of liquefaction, delayed compression and the 'pressure acting in the solid phase', as we now call the effective stress. The world remained unaware of this work until 1925 when Terzaghi published his findings in *Erdbaummechanik auf Bodenphysicalischer Grundlage*, a book that marks the beginning of soil mechanics as a science.

Figure 1. Scene of the train accident at Weesp in 1918.

On 13 September 1918 at Weesp in the Netherlands a serious railway accident took place that had a lasting social and political impact (Fig.1). The press reported: "Due to collapse of a railway embankment over 95 meters a passenger train rolled seven meters down from the rail near the bridge over the Merwede Canal (Fig.2), the locomotive bumped into the bridge and several wagons were splintered; 41 were killed and 80 heavily injured. Help and equipment arrived soon at the location, which offered a touching scene. Queen Wilhelmina visited the wounded in the hospital and Prince Hendrik made his way to the site."

Earlier, in 1892, a similar accident had taken place: the collapse of a railway embankment near Beek-Elsloo in the Netherlands. There were no victims, but people's trust in the safety of train traffic was shattered. Restoring confidence was urgent for the country's best, but disputes in the government led to a clash between geologists and engineers, i.e. between science and practice. Minister Dr Cornelis Lely, an engineer himself, stated in 1894 during the presentation of the governmental transportation budget: "… Everything is and will be done to obtain complete certainty and the government has asked advice from expert geologists acquainted with the local situation, in order to inform the engineers about local soil properties. This does, of course, not imply that the geologists' advice, where they believed to serve technical matters, entering in fact strange territory, could or should be followed. Since building a railway is not the work that one could trust to geologists …". The controversy remained and no progress was made until the accident at Weesp on September 13^{th}, 1918. The parliament assigned next day a committee to investigate the bearing capacity of soil, under leadership of the former Minister Lely.

The embankment was constructed in the period 1886 to 1889. How could such a collapse take place without any previous signs of weakness by cracks or small settlements? A visit the same day to the site showed the committee members that the embankment did not slide but more or less flew out over the lower area. They noticed that the sand in the embankment itself was still saturated with a water level about one meter higher than in the ditch. Observation pipes were placed and borings were made. The report four months later showed an intelligent and sober approach, and hardly any theoretical consideration.

The embankment had been constructed by creating a coherent sand body in the original peat soil. The sand body subsequently compacted the seven-meter peat layer to 1/8 of its original thisckness (Fig.3). The committee noticed that the sand body was surrounded underneath and at the sides by less pervious soil.[1] Water of the canal could enter the sand embankment easily, since the clay box meant to seal the connection was not deep enough. So, the water table in the embankment was at the canal level, much higher than the groundwater table! Also rainwater could easily enter through the open railway bedding. A worker of the train company, who stated that in cold winters the ditches parallel to the railway near the bridge never froze, confirmed this situation.

Figure 2. Bridge on the Merwede Canal in 2000.

However non of this could not explain the collapse occurred 30 years after construction. The committee found the cause to be the extraordinary and unprecedented weather conditions: ten days of extreme rain (100 mm), leading to a canal level rise of 30 cm and saturated soils. The passing train on 13 September 1918 at 10.30 shook the soil, which subsequently 'flew out'.[1] The committee pointed out that actually the construction had been dangerous from the beginning and that with time the side roads, built on peat, had sunken away gradually, leaving the slopes with less support. The committee advised the following remedial measures: sheet piling to close off the connection between canal and embankment, a drainage system, and additional banking to support the slopes. Even with the limited soil mechanics knowledge available in those days the committee had chosen the correct measures.

[1] It should be noted that in those times the decrease of permeability of peat on compaction and the risk on liquefaction as result of the construction method (dumping loose sand) were unknown.

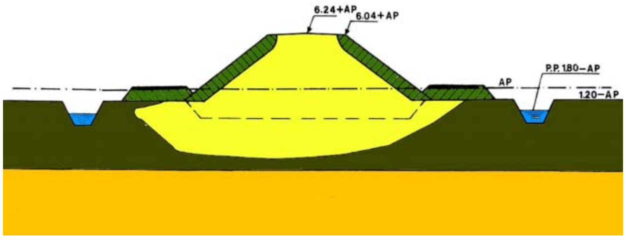


Figure 3. Railway embankment at Weesp, in 1918

The accident was for the Royal Institution of Engineers (KIvI) an inducement to install a Committee for Building Ground Research, again under the leadership of Lely and with him Prof. A.S. Keverling Buisman, who would later become the pioneer of Dutch soil mechanics. The committee's task was not easy: define which loading can be admitted to soil while considering stability, durability and economy, and what are the changing conditions of soils during and after construction that may jeopardize its safety. Soon three subcommittees were established and Keverling Buisman, then at the age of 29 a professor in applied mechanics at Delft University, participated in two of them, 'theoretical approach of bearing capacity of building ground and sand' and 'methods to physically test the bearing capacity'. Comprehensive research on soil mechanics started here, in the Netherlands.

In December 1931 during a general meeting of the Royal Institution of Engineers the attendees visited Keverling Buisman's small laboratory for soil mechanics at the Technical University of Delft. In his introduction he tempered the high expectations by pointing at the modest scale of the laboratory, where almost without financial aid or means research was undertaken. "I like to remind you that the mechanics of soils during the last hundred years proceeded little further than Coulomb's shear plane theory, with some refinement by Rankine, but calculations today are merely based on Coulomb's idea." Keverling Buisman mentioned the strong progress of mechanics in other materials, but knowledge of soil remained limited to simple equilibrium analyses. He noted that there had been hardly any improvement on the laws that control the soil deformation behavior (Bokhoven, 1990).

This shortcoming was also noticed in other countries. In the US, in Germany and in Sweden a similar commission for soil investigation was established around 1913, after the dramatic collapse of embankments. The Statens Järnvägers Geotekniska Commission in Sweden stated in its final report on the stability of slopes in 1922 that some pore water must be squeezed out from saturated clay, when loaded more than before. At universities elsewhere research on soils was starting to be performed.

A breakthrough came with Terzaghi. Keverling Buisman was in fact one of the first to have been introduced to Terzaghi's work in April 1924 at the 1st International Congress for Applied Mechanics at Delft, where Terzaghi presented his new theory of hydrodynamic stress (Terzaghi, 1924). In his lecture Terzaghi showed the measured mechanical behavior of clay (pore volume change under loading-unloading-reloading conditions), a consolidation test, the hydrodynamic stress (effective stress concept) and the solution of the consolidation process in the test, as well as the implication of the theory of hydrodynamic stresses to borehole stability, apparent cohesion and the development of pile friction in clays, referring for further details to his book *Erdbaummechanik auf Bodenphysicalischer Grundlage*, which appeared in 1925.

"Terzaghi's book", Keverling Buisman said, "put all committees in a second position. Therefore, every coming engineer should be introduced to the basic principles of this new science enriched with local practical experience."

In 1933 Keverling Buisman reported on the train accident at Weesp based on Terzaghi's findings and new research data from his laboratory, determining sliding and deformations in a more proper manner. The accident at Weesp was in the Netherlands the start of a systematic approach to scientific research in soil mechanics. In 1934, with the support of Keverling Buisman the Laboratory of Soil Mechanics was founded, now GeoDelft, at the service of the authorities and industry, with a focus on the special conditions of the Dutch soft soils. It developed well, as is recorded by the words of Carlton S. Proctor during the first International Conference for Soil Mechanics and Foundation Engineering in 1936 at Cambridge, Massachusetts: "It has been thought that because of the very excellent work being done a conference of this kind might be held in Holland, if Holland desires to invite the Conference. That is certainly an ideal location and there is certainly a great deal of excellent work being done there, as evidenced by the splendid papers presented here from Holland." Because of the Second World War, during which Keverling Buisman died in Indonesia, this conference was postponed. It was held in 1948 in Rotterdam.

1.2 *Nature surprises*

On the night of 26 August 2003 at 02.00 an embankment slid away with a loud snap, after months of severe drought. The water of the canal inundated a part of the village of Wilnis in the Netherlands (Fig.4). The responsible Waterboard took immediate action, dammed the canal and evacuated part of the population. No one drowned, but the damage was later put at 60 million euro.


Figure 4. Canal embankment collapse at Wilnis, 26 August 2003.

After a century of soil mechanics investigation and practice, in the Netherlands particularly on dike technology, how could such an event occur unforeseen? The lowlands of Holland, as someone said, seems in jeopardy by water from four different fronts: by high rivers, stormy seas, heavy rains, and also from a lack of water, the last one an unexpected surprise. During that period some 15 other similar embankments were also found to be in danger, showing local collapse, cracks and leakage.


Figure 5. Typical polder landscape due to peat mining in the past.

These embankments were of a typical construction, built from peat and clay centuries ago in the original swamps, embedding a lowland canal to which the surplus water of the area was and is being pumped and transported to the sea. This type of regional dikes became needed because the peat was being mined for salt production and turf. When the peat mining stopped the resulting lowland, called polder, was used for cattle (Fig.5). Now, the region around Wilnis, its surface settled about 1.4 meters below canal level, has been developed into a modern living area.

Such a peaty embankment is characterized by a very moderate slope, around 1:10 (Fig 6). Peat is light and if not compressed it is relatively permeable. To perform its function it must be saturated, and usually the infiltration from a steady canal level provides sufficient recharge to maintain the water content. When peat dries out, however, it shrinks significantly and its weight becomes like cork. Investigation after the event revealed that shrinkage and uplift probably caused the slide (Bezuijen et al., 2005).

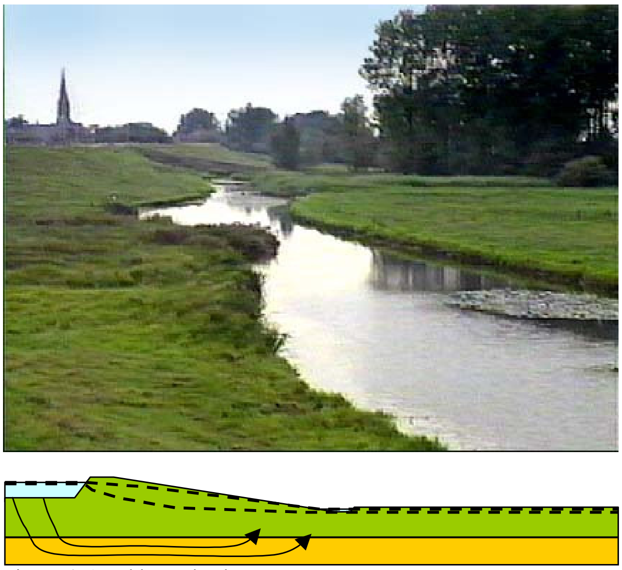


Figure 6. A polder embankment.

In 1960 a similar canal embankment collapsed in Tuindorp-Oostzaan near Amsterdam, in this case due to a broken water-pipe line in the dam. The lack of knowledge of the stability of these embankments became manifest. The responsible Ministry founded Technical Water-defense Advice Committee, TAW, in 1965, still in operation today. It launched in 1969 a systematic investigation to determine the actual state of polder embankments and to define guidelines for their evaluation, design, improvement and management. Over 5.400 km of such embankments exist in the Netherlands

The investigation was completed in 1993, after some 24 years. Polder embankments considered to be most relevant, with a total length of 1703 km in 200 individual lowlands, had been checked, 1407 km was in a good state, 157 km were already being improved and 156 km were found to be unsafe. The embankment in Wilnis was checked in 1973 as part of the project. About 90% of the embankment appeared to be unsafe and most of it was subsequently improved since, according to the guidelines. However the assessments for the project were based on scenarios for high water levels and not for dry conditions. Following the Wilnis failure, it is clear that our knowledge of the mechanical and chemo-biological behavior of peat is poor (Fig.7).

No one thought then to consider dry embankment behavior. Moreover, extreme high river levels in 1993 and 1995, see Figure 28, shifted the priority towards river dikes, away from regional canal embankments. In 2003, after Wilnis, it became clear that the archives of the 24-year polder embankment study were not only incomplete, but knowledge of details of the results was not or only poorly available to the local authorities. If and how the embankments marked as unsafe had been improved was also not clear.

Figure 7. Peat, its mechanical properties are hardly known.

Information, knowledge and experience are not sufficiently transparent and not properly disseminated. They seem to evaporate with time. Moreover, the once-gained insight is not updated over time, or as conditions change we don't learn from our experience ... nature may have still many surprises.

1.3 *Pluriform processes, in space and time*

When observing specific phenomena in nature, it should be realized that all phenomena that may be present will be present. Nature is pluriform. Field variables, like pressure, velocity or temperature, will change in time and space, and these changes can be measured, but no one aspect can be observed separately. In a theoretical approach we use concepts that are specific and attributed to chosen phenomena, treated independently. In accordance with our understanding of physics and using the tools of mathematics, we assign principles and laws to describe a specific behavior, and the result is a model where time and space changes attributed to this behavior are expressed. By superimposing such effects reality is approximated, the approximation improving as more relevant phenomena are considered. The superposition is, however, complex.

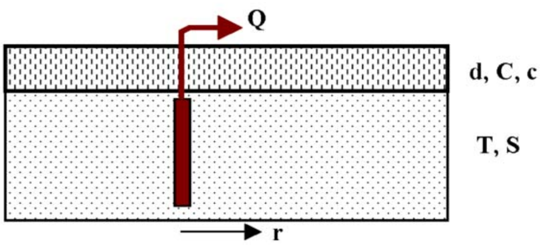


Figure 8. A well in a semi-confined (leaky) aquifer system.

The following example of a closed form solution to the problem of predicting pore pressures due to pumping illustrates this compelxity. A well function describes the pressure drop p [Pa] at position r [m] and time t [s] in a semi-confined aquifer for a constant well production Q [m^3/s]

$$p = (Q\gamma/2\pi T)\, K_0(r(TC)^{0.5})$$

Here, K_0 is a Bessel function

$$K_0(y) = \int_0^\infty exp(-x-y^2/4x)\, d(ln(x))$$

Thus

$$p = (Q\gamma/4\pi T) \int_0^{\infty} exp(-x - r^2(TC)^{-1}/4x)\ d(ln(x))$$

This model describes two physical processes, the flow in the aquifer and the leakage from the aquitard. Here, model parameters are: T the transmissivity [m^2/s], γ the specific fluid weight [Pa/m], and C the hydraulic resistance [s]. T controls the aquifer flow and C the leakance (leakage trough the top layer). The formula shows that the space r is scaled by $(TC)^{0.5}$ and the pressure p by $Q\gamma/4\pi T$. The formula is based on the principle of mass conservation and the empirical law of Darcy. Hence, the process is determined by the intrinsic model parameters γ, T and C. The function *ln* reflects the shape of the pressure in space. If also time-dependent processes play a role, by storage effects in the aquifer (sand layer), the corresponding well function based on conservation of mass and two laws (Darcy, Hooke) becomes, known as the Hantush well function

$$p = (Q\gamma/4\pi T) \int_u^{\infty} exp(-x - r^2(TC)^{-1}/4x)\ d(ln(x))$$

with $u = r^2 S(4Tt)^{-1}$

Here, the additional model parameters are S the aquifer storativity [1] and the time t [s]. One may still recognize the space scaling, but the time is involved in a parameter group including the space coordinate r, in the term u. Including also storativity in the aquitard, i.e. consolidation, the corresponding well function becomes (Barends et al., 1987)

$$p = (Q\gamma/4\pi T) \int_u^{\infty} exp(-x - r^2(TC)^{-1}\xi coth(\xi)/4x)\ d(ln(x))$$

with $u = r^2 S(4Tt)^{-1}$ and $\xi = d(2ct(1\text{-}u/y))^{-0.5}$

Here, the additional parameters are c the aquitard consolidation coefficient [m^2/s] and d the aquitard thickness [m]. To simulate reality, i.e. when all the processes take place, the different concepts are in fact superimposed. The superposition of different processes is complicated. It is not a simple algebraic addition, since the various processes interact. There is no alternative, because field measurements contain integral information of all the processes. When validating a model by a field test corresponding model parameters can be calibrated and a new prediction can be made to support a design or a decision. Hopefully, all significant phenomena will have been adequately incorporated in the model, as field calibration will not tell you. If not, predictions (extrapolations) will be false.

Consider a well test in a geohydrological two layer system (Fig.8). The test is performed in the field so that the variance in geological stratification and in ground properties can be accounted for, and parameter values obtained by regression analysis based on a schematic profile automatically incorporating natural inconsistencies to a certain extent.

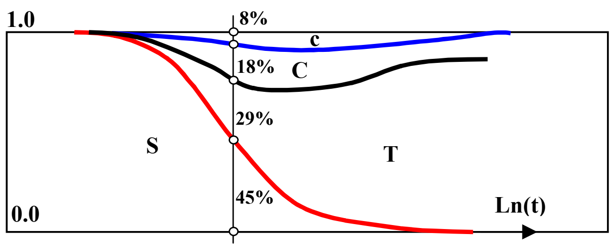


Figure 9. Relative contribution to the pressure drop variance.

Advanced probabilistic tools are adopted to elucidate the specific uncertainty of the parameters involved. A mean point approach is used to define the confidence interval for the reconstructed drawdown according to the field measurements. Regression analysis is applied to find the relative contribution of the various characteristic model parameters to the variance in the measured pressure drop. The result shows that the four different processes play a role within their specific time regime, first elastic aquifer storativity (S) and then aquifer transmissivity (T). Aquitard consolidation (c) and aquitard leakance (C) have a smal influence, with a maximum of about 10% and 20% at a certain moment (Fig.9).

The graph shows that, if measurements are not complete, the influence of some phenomena (parameters) may not be recognized and would not be clear from field measurements without proper interpretation. In this case, it is practically not possible to obtain accurate parameter values related to the induced consolidation, and data related to leakance can only be obtained by a long-duration test.

The observational method, advocated by Terzaghi and nowadays becoming more and more popular, can be successful and can lead to real advances in insight, especially if combined with the development of advanced interpretation methods, such as geostatistics, probabilistic methods, neural networks and fuzzy logic. A powerful method, still hardly explored for soil mechanics, is self-similarity (Barenblatt, 2003). Many phenomena in nature, engineering and society when seen at an appropriate intermediate distance, in space or time, exhibit the remarkable property of self-similarity, i.e. reproduction as scale changes. When knowing the nature of such laws, model formulation becomes easier and observed physical behavior can be more deeply understood.

1.4 *Multi-disciplinary cooperation*

Though not directly related to the field of geotechnics the development of insight into land subsidence phenomena is an example that emphasizes the importance of multi-disciplinarity. Some 10 years ago several light earthquakes were noticed in the Province of Groningen, Netherlands, an area above a large deep gas field. Earthquakes in this area are unusual. A national multi-disciplinary commission was established. It succeeded in elucidating the link with gas production and establishing a reliable method for the determination of the maximum possible induced earthquake intensity to be expected and its effect on the environment. A close cooperation of several disciplines proved indispensable to reach that goal. To solve the problem, the various disciplines involved in the different focus areas were

	Reservoir	**Surface**	**Environment**	**Prediciton**
Reservoir eng	***	*	*	***
Geology	***	**	**	*
Geodesy	*	***	*	*
Geotechnical eng	*	***	***	**
Hydrology		*	***	**
Construction		**	***	*
Seismology	**	***	**	**

* level of relevance

Some 100 million years ago, the area was covered by swamps and forests. Thick deposits on layered remnants of this flora made it sink, providing a perfect environment for fossil fuel formation. Gas migrated upwards under a sealing rock-salt layer into a large sandstone reservoir. The gas was discovered in 1953 and exploitation started in 1963. The Groningen gas field consists of a large field of 900 km^2 and several smaller fields at a depth of 2900m (Fig.10). The overburden pressure is 65 Mpa, originally 50% exposed to the gas (pore pressure) and 50% to the sandstone (effective stress). The gas volume is estimated to 2.5 10^{12} m^3 of which now 50% has been produced. During recovery the pore pressure drop is in the range of 30 Mpa on account of the effective stress in the sandstone. Consequently the reservoir will compact with time leading to land subsidence. In fact, this process will proceed in principle according to Terzaghi's theory of hydrodynamic stresses, except that the pore fluid flows horizontally.

Figure 10. The Groningen gas field, discovered in 1953.

Groningen consists of lowlands, many of which are below sea level. The surface water management is delicate, and accurately controlled within centimeters. The levels of roads, bridges, quays, dikes and embankments are likewise preserved. Subsidence of some decimeters has serious implications for the environment.

An extensive research program was initiated to investigate the reservoir compaction. The first evaluation in 1971, performed with analytical linear-elastic theory predicted a maximum subsidence of 100cm in the year 2050 (Geertsema, 1973). Two disciplines were involved: reservoir engineers and geologists. Doubts about the reliability of the (laboratory) parameter values of the compaction coefficient of core samples led to an extensive field measurement campaign. This consisted of measuring the reservoir compaction using radioactive bullets and gamma-ray sounding, and of precise surface leveling applying optical and hydrostatic methods. The discipline geodesy became involved. Furthermore, the natural shrinkage of the topsoil layers was measured using a 400m cable system (extensometer) and precise gravity measurements were conducted. In 1975 the results permitted a significant reduction of the predicted maximum subsidence to a new value of 30cm in 2050.

However, new knowledge inspired new vision. The so-called rate effect caused (the change in material behavior with respect to the rate of loading) now led to a new third prediction, this time higher again. Since the pressure drop in the reservoir takes place over a relatively short period with respect to the geological loading, there will be a change in the rate of compaction over time, and the initial subsidence will be stiffer and therefore not representative of the ultimate subsidence. In 1985 the improved prediction gave a maximum of 65cm in 2050. The rate effect measured in the laboratory, however, appeared not realistic in the field, as was demonstrated by the continuing geodetic leveling campaigns every 5 years. The latest insight in 2003 states, that the maximum subsidence is likely to be 38cm in 2050, with an accuracy of 5cm. This history shows that by close observation using the best knowledge to hand and by continuing research involving more disciplines, the development of insight into the compaction process led to a significant improvement in accuracy (Fig.11).

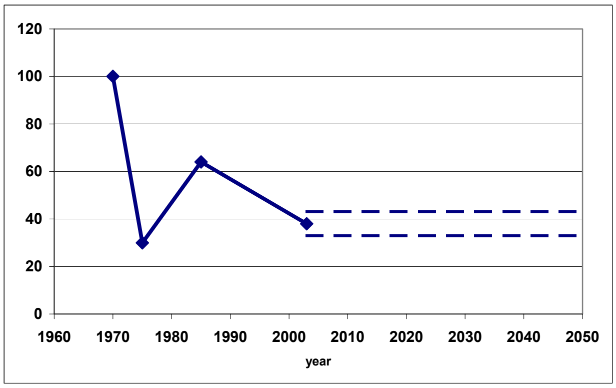


Figure 11. Development of the accuracy of the predicted maximum subsidence, expected in 2050.

The potential damage to the infrastructure due to differential settlements was investigated by applying statistical techniques. Gas withdrawal causes a subsidence bowl at the surface, and the water level management had to be adjusted from area to area. Because subsidence causes tilting of the land surface at the edge of the bowl, the groundwater change will not be uniform and differential effects may occur. The research focused on the characterization and the evaluation of the induced settlements, on the determination of the probability of damage, on information essential for the judgment of claims, and on remedial measures. Three more disciplines now became involved: hydrology, geotechnics and construction engineers.

Hydrologists studied the required improvement of the water systems, geotechnical engineers characterized the soil profiles and foundation aspects, and construction engineers the sensitivity of the various structures to settlements. The probability analysis showed a potential damage to 34% of the existing structures, in some unfavorable situations. Limits to the allowable changes of groundwater table were established: for sandy soils a maximum of 30cm, for clayey soils 20cm and for peaty soils 10cm. With this practical approach the potential damage was reduced to a maximum of 5% of the existing structures and buildings and the required adjustments of the water systems could be defined in accordance with the local land subsidence (Fig.12). In 1989 the polder authorities were the first to put forward a claim of 50 MEuro for works on the sea dikes and the regional water systems, including weirs, pumping stations and raising levels of dikes, embankments and bridges. This has now been completed.

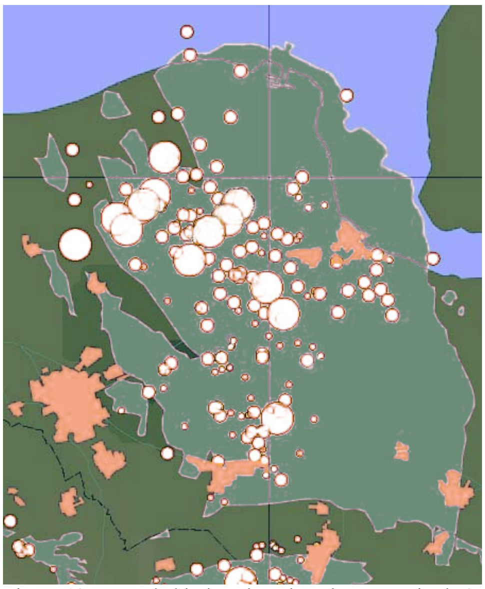


Figure 12. Recorded induced earthquakes, magnitude 2 to 3.5.

The northern provinces became exposed to mild earthquakes after 1986. People became afraid, expecting a large earthquake. As it was not clear what the cause was, a network of seismometers was installed. Seismologists now became involved. In 1991 the Dutch Parliament ordered a study to clarify the cause and to forecast future earthquakes (Boa, 1993). The complete statement of the problem incorporated identifying the cause and the repercussions of the surface vibrations as well as the prospects of making acceptable predictions and recordings of earthquakes, to be resolved by a collaboration of disciplines. The question regarding the relation between gas production and earthquakes was resolved by calculating stress changes resulting from the deformations due to the reservoir pressure drop in sophisticated mathematical models, including shifting along (potential) faults.

The geological environment, particularly the behavior of the salt-rock formation, was an important aspect. Its viscosity could cause a redistribution of stresses and deformations in the overburden reaching far beyond the immediate vicinity of the gas field, outside the usual influence area of the induced subsidence. It was found that, above salt domes, induced geological faults can be reactivated by gas production and this can cause moderate earthquakes (Fig.13). From seismological information and geodynamic modeling the maximum earthquake magnitude was established to be about 3.5 on the Richter scale.

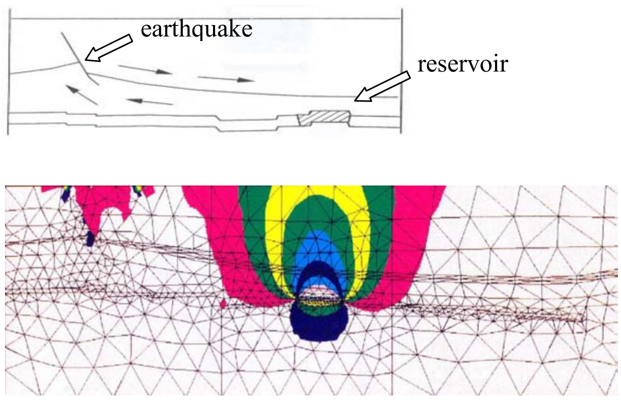


Figure 13. Simulation of deep-mining triggered earthquakes; vertical displacement contours (tinted zones); reservoir at 3 km depth.

The Groningen case history shows that close and continuous observation of the surface behavior is important. The development of insight and comprehension of the intricate processes involved shows that understanding is a matter of time, of multi-disciplinary cooperation, of continuous control and re-evaluation, and requires a critical attitude towards predictions, causes and consequences. For the land subsidence effects due to deep gas mining multi-disciplinary cooperation went as follows

	1960 1970 1980 1990 2000
Reservoir eng	****************************
Geology	****************************
Geodesy	******************
Getechnical eng	************
Hydrology	************
Construction	************
Seismology	*********

This experience teaches us that multi-disciplinarity becomes effective only after differences in jargon and vested interests are overcome and there is solidarity towards a common goal is settled. The required negotiation and communication to achieve this stage should not be underestimated.

1.5 *Subjectivity*

Interpretation of an observed pore pressure response due to changing water levels can be highly subjective, depending on the possible arbitrary choice of the model representing the reality. An example is presented here concerning cycles in groundwater pressure as a result of tides. The response of two piezometers *HA* and *HB* placed perpendicular to the coast at a mutual distance *x* is shown Figure 14.

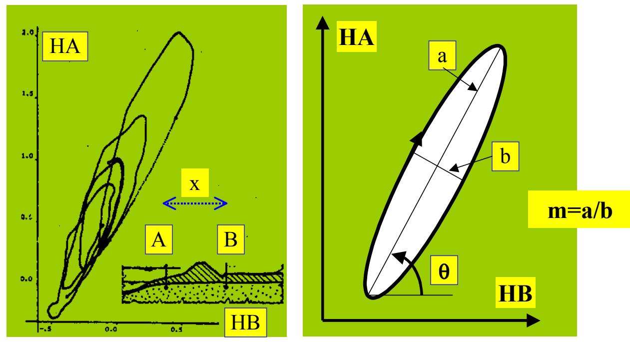


Figure 14. Observed tidal response and a theoretical model

The inclination of the ellipsoidal shape is a function of the decay expressed by *ln(f)* and its diagonal ratio *m* is a function of the delay *g*. Elaboration of the analytical formulation of a tilted ellipse in terms of inclination θ and the diagonal ratio $m = a/b$ gives (*H* is the amplitude of the rivel-level fluctuation)

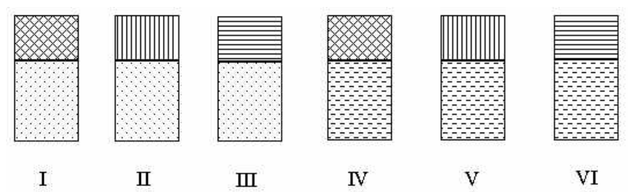
$$HB = H \exp(\ln(f)) \cos(\omega t - g)$$

$$HA = H \cos(\omega t)$$

$$f = ((1+m^2\cot^2\theta)/(1+\cot^2\theta/m^2))^{0.5} \approx \tan\theta$$

$$g = \arctan(2(m^{-1}-m)/\sin(2\theta))$$

To link this type of field observation to intrinsic physical phenomena, i.e. to find a suitable prediction model, the following approach may be adopted. The geological stratification is schematized in a two-layer system, one sandy layer (aquifer) and on top a clayey layer (aquitard). Both layers have a certain permeability and compressibility, which in the sandy layer induces phenomena of storativity and compaction and in the clayey layer consolidation and compression. One may disregard or include any of these particular phenomena and doing so, six geohydrological systems can be identified.



I a rigid permeable aquifer with an impervious aquitard;

II a rigid permeable aquifer with a rigid pervious aquitard;

III a rigid permeable aquifer with a compressible pervious aquitard;

IV a compacting permeable aquifer with an impervious aquitard;

V a compacting permeable aquifer with a rigid pervious aquitard;

VI a compacting permeable aquifer with a compressible pervious aquitard.

Assuming vertical compaction and horizontal flow in the sandy layer and vertical consolidation in the top layer a general analytical solution can be found. It has the following form

$$HB = H \exp(-\beta x/\lambda) \cos(\omega t-\alpha x/\lambda)$$

Here, λ is the so-called leakage factor, and α and β are related to the various geohydrological systems; α to the delay (retardation) and β to the decay (amplitude decrease). In all cases the same type of solution is found. For a specific situation, i.e. estimated practical values for permeability, storativity and consolidation, the corresponding values of α and β become

Schematisation	α	β
I	**0.00**	**0.00**
II	**0.00**	**1.00**
III	**1.41**	3.45
IV	**1.00**	1.00
V	0.71	1.23
VI	2.22	3.84

Bold numbers are constants

Since the retardation α is less significant, the decay β is used to calibrate the parameter λ according to

$$\beta x/\lambda = \ln(f) = \ln(\tan\theta) \qquad \text{or} \qquad \lambda = \beta x/\ln(\tan(\theta))$$

The table shows that a large difference is found for λ taking θ from a field measurement and β from a certain geohydrological system. In geohydrology and in reservoir engineering one uses model V (Hantush or Theis function). In geotechnical engineering one uses model III. Obviously the two calibrations give a difference of a factor 2.8, a large discrepancy, which cannot be discovered in the observation itself. The most realistic model is model VI, which does not much differ from model III. As a consequence, extrapolation with a well-calibrated but incorrect model may give rise to unexpected behavior. This is often the reason behind failure and damage. This example illustrates that interpretation of observed behavior depends on the applied model, which is in fact a subjective choice. Consequences of this subjectivity are easily missed.

1.6 *Misunderstanding*

The observed transient excess pore pressure response in earth river dikes due to cyclic tidal water level changes show a damped response with, surprisingly, a negative retardation (the peak response occurs earlier than the peak loading). Already in 1904 Honda noticed a negative retardation in the potential tidal response in Yokohama and in 1916 Friedrich observed the same in Lubeck. Unknown subsoil water streams were thought to be the cause! In 1933 Franx noticed a similar behavior during construction of the Park sluice in Rotterdam, and in the same year Steggewentz wrote a PhD thesis on the tidal response. No explanation was offered. Much later, De Lange and Maas (1986) found an explanation for the negative retardation based on the principle of superposition for rivers with a limited width.

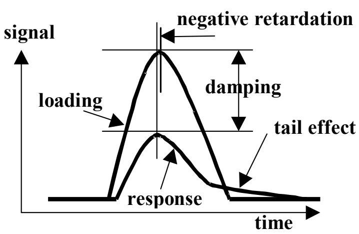


Figure 15. Peculiar transient groundwater response

Beside the negative retardation, the pore pressure response to a non-cyclic water level rise also shows a peculiar tail at the end of loading (Fig.15). Both phenomena were finally understood after a close inspection of the physical process that takes place, in fact, self-propelling storage effects, related to Terzaghi's effective stress principle (Bauduin and Barends, 1987).

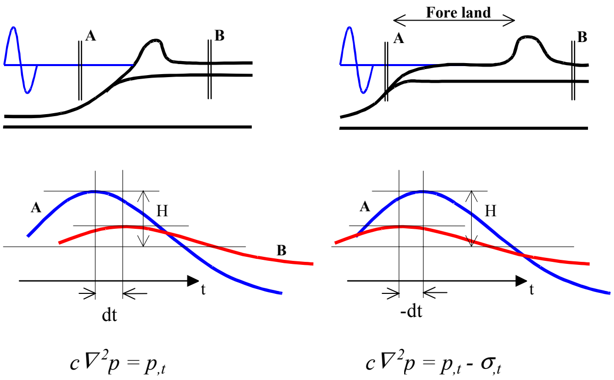


Figure 16. Positive retardation, boundary loading (left) and negative retardation, direct total loading (right)

The loading can, in fact, be imposed as a boundary condition or as an internal condition (direct total loading) in the case of a submerged foreland (Fig.16). The boundary condition (left) shows positive retardation and the internal condition (right), which has a large foreland, negative retardation. The understanding that the maximum induced pore pressure under the lee-side of a dike may occur earlier than the maximum water level in the river, was crucial in 1995 for the decision when, after critical high river-waters, evacuated inhabitants of the Dutch cities in danger of inundation could safely return to their homes.

1.7 *Opportunism*

Geotechnical aspects play a key role in the overall stability and functioning of coastal protection works. However, the principles of soil mechanics were rarely applied in the design of rockfill structures, except in relation to the subsoil. Instead, attention focused on the local stability of rock units under hydraulic forces due to free water motion and due to seepage forces. The failure of some large structures in the late seventies and the early eighties, the need to apply medium-quality rock and widely graded rock, and the growing attention to composite breakwaters inspired a new interest to apply geotechnics to the problem of hydraulic rockfill structures.


Figure 17. Breakwater at Sines, the world's largest, after failure in 1982

One specific case of studying the early failures, widely reported at the time, concerns the collapse of the West Breakwater at Sines (Fig.17; Barends, 1994). An overview of the present-day state of the art is reported in the Coastal, Estuarial and Harbor Engineers' Reference Book (1994).

Numerical models have been developed which are capable of assessing the time-dependent mechanical processes in breakwaters. The physical background of these models can be described with the one-dimensional momentum-conservation and mass-conservation equations. The equations describing the flow field outside the slope are (symbols are shown in Fig.18):

$$u_{,t} + u \bullet u_{,x} + gH_{,x} + g\tan\theta + f\,|u|\,u/2H \;\; + w(u-q) = 0$$
$$H_{,t} + (Hu)_{,x} = w$$

and the equations for the porous flow field are:

$$\zeta\, q_{,t} + (\lambda/n) q \bullet q_{,x} + ngh_{,x} + ng(a + b\,|q|)q \;\; + w(q-u) = 0$$
$$nh_{,t} + (hq)_{,x} = -w$$

The value of w is related to q along the submerged part of the slope:

$$w + q\tan\theta = 0$$

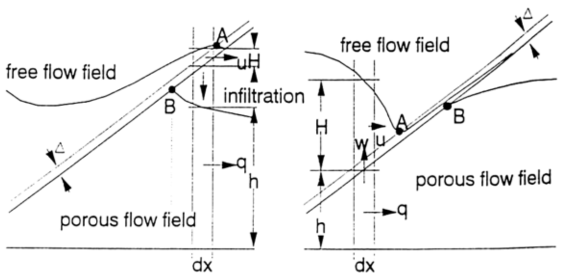


Figure 18. Schematization of wave run-up and rush-down

Where the free flow field (run-up) exceeds the internal phreatic flow the value of w is determined by infiltration, and where the free flow field (rush-down) is faster than the internal flow the value of *w* is absorbed in the seepage face. The meaning of the symbols in the equations is shown in Figure 18, and ζ is the (virtual) mass coefficient, n the porosity, θ the slope of the free water bed, *f* the friction factor and *a,b* the coefficients of the Forchheimer porous flow law. By using proper values for the maximum phreatic run-up and rush-down and a certain water film limit (Δ) of the free-water motion on the slope a realistic simulation can be achieved. The proper values are found by comparison with experiments.

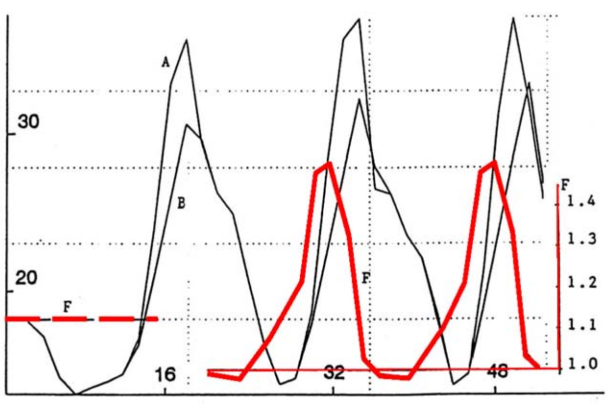


Figure 19. Wave motion on a slope: outside (A) and inside (B); and the corresponding stability (F), static state (left) and dynamic state (right).

Probabilistic analysis offers a method to determine the risk of a slope failure under wave attack. Using the afore mentioned design tools for evaluating the wave induced flow inside and outside the breakwater a study was undertaken to establish the effects of various parameters, such as the wave height *H*, the wave period *T*, the crest width *B*, the slope angle α, the still water depth *D*, and the armor/core interface friction angle φ. A total of 33 different cases (water depth: 4 - 8m, waves: 2 - 6m, slope: 1/1.5 – 1/2) were simulated using a model for assessment of the dynamic flow field and a model for assessment of the corresponding dynamic slope stability factor (Fig.19).

By considering the normalized sensitivity using the results of the various cases in a comprehensive manner and by adopting realistic standard deviations for each parameter, the probability of slope failure was determined. This approach was followed for 6 cases. The results show the relative contribution of the design parameters to the overall probability of slope failure *PF*, and the corresponding ratio between the static and dynamic slope stability factor F_{dyn}/F_{stat}.

case	H	α	φ	D	PF	F_{dyn}/F_{stat}
10	0.09	0.48	0.41	0.02	0.026	0.87
13	0.12	0.21	**0.67**	-	0.112	0.80
15	0.01	**0.92**	0.07	-	0.230	0.88
18	**0.62**	0.01	0.31	**0.06**	0.640	0.70
20	0.01	0.94	0.06	0.02	0.370	0.80
31	0.03	0.66	0.31	0.05	0.069	0.81

The conclusions of this study were

- with increasing water depth *D* the minimum dynamic slope stability factor increases;
- the influence of the wave period *T* is not clear;
- for surging waves the minimum dynamic slope stability factor will slightly reduce with increasing wave height *H*;
- for plunging waves the minimum dynamic slope stability factor increases with increasing wave height *H* (surprise!);
- the slope angle α and the interface friction angle φ have effects consistent with engineering intuition;
- the effect of the interface friction angle φ does not change during the wave attack;
- the data was insufficient to obtain a trend for the crest width *B*;
- the minimum dynamic stability factor F_{dyn} is significantly less than the static stability factor F_{stat}, ranging from 10% to 30%.

From this study it became clear that the dynamic slope stability does not reveal simple predictable trends. For the contractors and consulting companies this last comment alone was sufficient. The new design rule became: calculate the static slope stability with a standard method and adopt a margin of 25% to account for wave-dynamic effects. The research stopped. As a scientist this conclusion is unsatisfactory, since few cases were analyzed, many aspects are still unclear and the uncertainty is rather large. As an engineer the research findings are rather complicated, further research would be costly and incorporating the uncertainty in a practical manner seems the best for the time being.

1.8 *The unseen*

In 1995 a grout-column retaining wall protecting a deep building pit near a river collapsed suddenly, unforeseen, after months of satisfactory performance. A new metro station was being built around an existing metro tunnel while train services continued uninterrupted, at more than 10 meter below groundwater level. Investigations after the event revealed that a combination of several factors gradually caused a critical situation: leakage, consolidation, erosion, piping, pump failure, and column fracture. By chance pore pressures had been measured continuously. They reveal the unseen gradual process of local deterioration, which took place along the interface of the existing metro tunnel and the subsoil. It is worthwhile to mention, that, if the erosion process should have caused such failure two month later, nothing would have been noticed and nothing would have happened, as by then the construction of the metro station basement would have been completed.

The metro tunnel itself has been built in the sixties applying the sinking-trench method using prefabricated tunnel segments of $10x6.2x90m^3$. The foundation consisted of special vibropiles with adjustable heads, lifted them under water by grouting after placement of the tunnel segments on temprary supports (Plantema, 1965). The tunnel leads the metro under the river Maas in Rotterdam. It operates properly. In 1994 a construction operation started to make a large underground metro station at the Wilhelmina Pier, Rotterdam, in the river bank, while the metro services ran uninterrupted; a complicated engineering task. The Dutch Minister of Traffic, Public Works and Water Management opened the metro station officially in spring 1997. It is still the deepest metro station in the Netherlands (Fig.20).

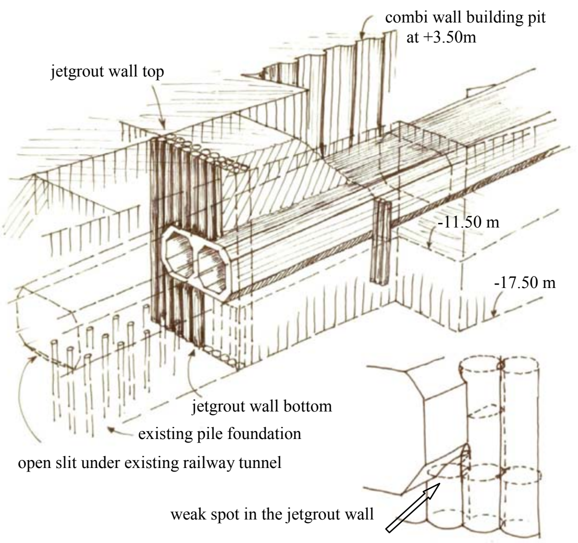


Figure 20. Building pit metro-station Wilhelmina Pier, Rotterdam

The building pit reached a depth of 11.50m. The soil was very soft and the water level was high and static. To prevent leakage several measures were taken, such as grouting the slit under the existing tunnel (an opening of more than 15cm was found), installing a solid retaining combi-wall, a deep pumping system, and around the existing tunnel installing a wall of grout-columns of 1.80m diameter by the VHP-grouting technique. Under the tunnel the closure was realized by boring a thin pipe through the tunnel at night. A sketch of the works is shown in Figure 20. To test the water tightness of the grout-column retaining wall a local shallow pumping system was placed (Fig.21). It had been in operation during the construction. From November 1994 until February 1995 the system functioned well. No clear evidence was observed that anything could go wrong. Several safety systems around and in the tunnel worked properly. No excessive displacements occurred.

However, in February 1995 after five months of uneventful performance, some water inflow was observed. Next, a pump broke down, a pronounced sand inflow was noticed, and after a temporary repair the grout-column wall locally collapsed. The subsequent mud and water inflow could not be stopped. Finally the building pit had to be put under water in order to repair the grout-column wall. Total damage was around 5 MEuro.

During the investigation of this accident all possible causes were considered, such as seepage under and around the wall, leakage through the walls, stability and strength of structural elements, flow under the existing tunnel, functioning of the pumping systems, climatic effects (rain, high river levels), vibration due to building activities (pile driving), inhomogeneity of the subsoil, and the quality and control of applied materials and construction methods. The conclusion was that an unfortunate combination of several factors led to the critical situation, and that it was hardly possible to understand that something was going on. The grout-column retaining wall was correctly functioning. Some minor leakage had been noticed right from the beginning, but this was handled easily by the installed pumping system. Since the wall had to function temporarily, the leakage was acceptable. This is normal practice for temporary structures.

The leakage and a possible small deformation of the deeper clay layer due to the deep pumping system (head drop of about 12m), may have given place to regressive erosion of the sand under the existing tunnel (piping), which was founded on piles in the sand layer underneath the clay. Small water and sand inflows would hardly be noticed during the excavation and construction works (open pit, it rained regularly).

It is assumed that with time the sand directly behind the wall under the tunnel at the sides was gradually eroded, and that under the large water pressure drop (about 10m), in the absence of local soil support, some parts of the grout-columns fractured, giving rise to a strong mud flow.

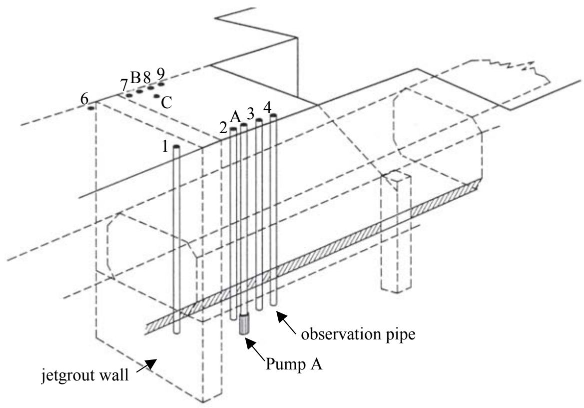


Figure 21. Temporary pumping system at the jet grout wall.

It simply chance that during the entire period of construction the pore pressures in eight observation pipes, installed in the critical zone, had been monitored. This information later gave valuable insight into the sequence of events. Consider the measurements in detail (Fig.22). A pumping test was carried out at the start of the works. This lasted for only 8 hours but was considered to have reached a sufficiently steady state. The permanent response developed significantly differently (viz. piezometers 2, 4, 7 and 9). In practice, the test was far too short. However, during October to December 1994 everything worked properly. In December something went wrong with the pumping system (viz. drift of piezometric levels).

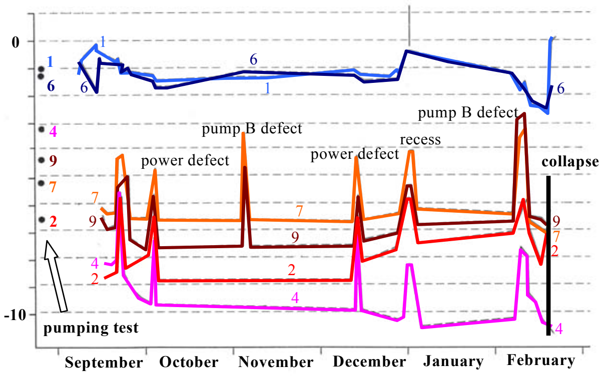


Figure 22. Historic data of the temporary pumping system

A groundwater flow simulation afterwards shows the difference in the corresponding porous flow pattern (Fig.23): the leakage became pronounced around pump B. Unfortunately, pump B failed at the beginning of February. An additional pump C, quickly installed, did not solve the problem; it in fact worsened the situation.

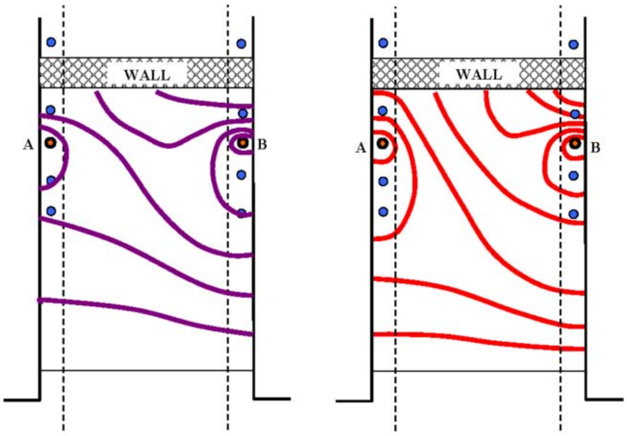


Figure 23. Sketched flow pattern changes under the exisitng tunnel (isopressure lines); in November (left) and February (right).

It has to be said that the changes in the pore pressures and porous flow pattern, noticed during the investigations afterwards, were at the time not considered alarming. No particular significant leakage or mudflow from under the tunnel was observed. The grout-column retaining wall was properly designed and its strength in combination with the soil support seemed sufficient. So, one could argue there was no reason to expect before hand, that such an erosion process was taking place.

The lesson from this example is that one should pinpoint before hand the most sensitive locations on any geotechnical works. A suitable monitoring procedure and its interpretation will give valuable information, including for temporary structures. It can show the moment when counter measures are required. This case shows that 'going through the notions' is not sufficient. Unseen processes, mostly occurring along interfaces between soil and structures or between different soil types, can be noticed in time by careful monitoring and expert interpretation. However, small changes in monitoring data are very hard to interpret and can give an illusion of stability, even at the moment of failure.

1.9 *Deep mystery*

After the Westerschelde tunnel was opened in March 2003 the last 'island' in the Dutch province of Zeeland became linked by a permanent cross-river connection. The design and the construction started in 1995. It was at the limits of present-day possibilities (Heijboer et al., 2004): a bored twin tunnel of 6600m length with diameters of 11m reaching as deep as 60m below sea level under very difficult geological conditions, in particular the loose sands and stiff clays of extraordinary composition. The public-private nature of the consortium, with the private organization NV Westerschelde (NVW), responsible for the construction and access roads, as well as for the technical management, maintenance and operation for a period of 30 years, and the Dutch Government acting as shareholder, was also quite exceptional. A consortium known as KMW (BAM infrabouw BV, Heijmans NV, Voormolen Bouw BV, Franki NV, Phillips Holzman AG, and Wayss & Freytag AG) designed and built the tunnel, and will maintain the tunnel for the first 10 years. The construction budget of about 750 million euro was exceeded by only 6%, which is fairly good for such a huge and unpreceded project.

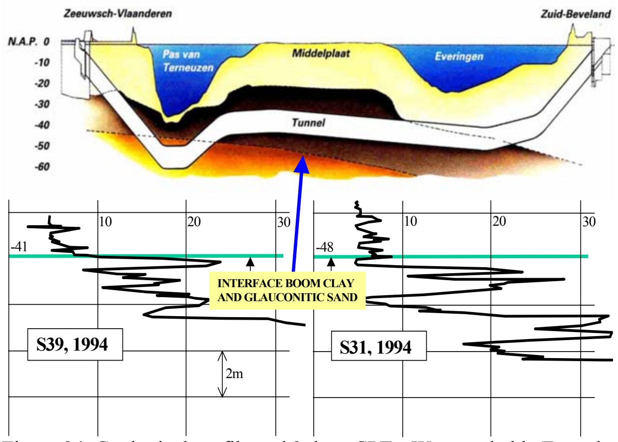


Figure 24. Geological profile and 2 deep CPTs, Westerschelde Tunnel

In many respects the construction was a pioneering project. The logistics were a great challenge since the civil fitting out of the tunnel immediately followed the boring process, including the 26 cross-connections, which were constructed using ground freezing techniques under extreme conditions. A bored tunnel at this depth had not previously been realized in soft sediments in Europe. Soil investigations included very deep cone penetration tests reaching 65m minus sea level through the Boom clay into tertiary glauconitic sands. Soundings in these sands showed a resistance with significant variation between 5 MPa and 45 MPa (Fig.24). This has a serious implication on the soil bedding of the tunnel shield and lining as is demonstrated next.

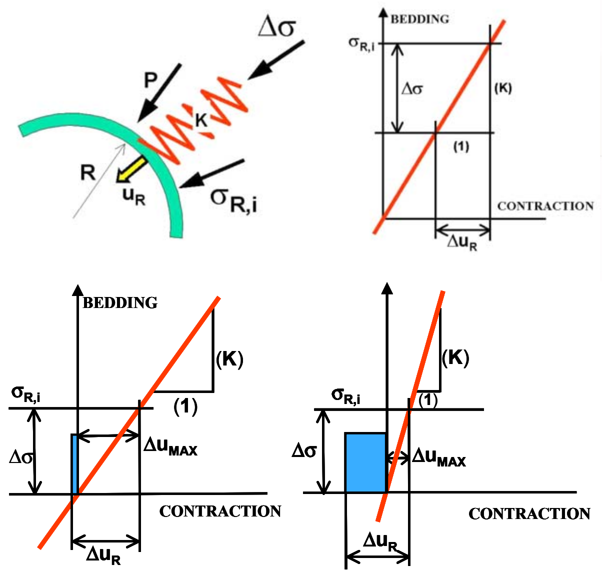


Figure 25. Tunnel shield design: Duddeck (above); (down) cavity dependent on soil stiffness: low stiffness (left), high stiffness (right).

The boring started in 1999 with two TBMs. In May 2000 in the Tertiary glauconitic sand structural deformations at the tail of the shields of both TBMs were noticed and some damage occurred. The theoretical air measure between the TBM and the tunnel lining was 85 mm. Deformation measurements showed that at a number of spots the tail of the shield almost touched the lining. Over a length of 4.5 to 5m (in the longitudinal direction of the shield, total length of 11.55m) the boring shield of the east TBM showed severe irregular deformations. The maximal deformation of the west shield was 40/50mm and the maximal deformation of the east shield was 52mm. Finally the west TBM stopped boring at ring 543 and the east TBM at ring 512, very near the deepest point (Fig.24). Measures were taken and boring continued. Despite these measures the deformations of the TBM increased to a maximum of 60 mm. As soon as the TBM went up, these deformations decreased.

The stagnation had cost serious delay and additional costs reaching 35 million euro. Both parties NVW and KWM started an investigation to find possible causes and work out who should finance this loss. Concerning the ground conditions and design approach the following observations were made. The design of the tunnel shield is based on Duddeck's method (Fig.25), which is a common state of the art. Original calculations showed sufficient soil bedding support for the shield under the extreme high water pressures (60m below sea level), when adopting low soil stiffness. This was the basis for the tunnel shield design. However, according to the NVW investigation, when adopting high soil stiffness, there is no soil bedding, meaning that under the very high pore pressures shield deformations (buckling) may occur. The soundings (Fig.24) show that the soil stiffness is strongly non-uniform and it is known that, particularly when there is significant silt or clay content, it is possible for cavities to remain unsupported in sands. Furthermore, a few case histories of tunnels constructed in loose clayey silty sands show that radial effective stresses may become very low.

Tertiary glauconitic sands can show much greater variation than one may imagine. Temporarily a void can arise, where the shield contact is released, or a very stiff reaction is generated, where the shield contact is intensified. Similar experience is found in pipe jacking: the boring hole is rather stable, but steering corrections are hardly possible. The clay content and density determine this behavior. NVW concluded that a combination of facts contributed to the excessive shield deformation: drift, glauconitic sand and high water pressure. The soil stiffness chosen in the design did not reflect the most critical condition at the lowest position. The extreme bedding (cavity) and high pore pressure condition there could have been foreseen, when the available soil data and experience had been considered with sufficient care. KWM's view was that the situation could not have been foreseen, that the execution of specific on-site soil investigation was extremely difficult and that high horizontal stresses (high K_0-value) were unknown. What really caused the stagnation deep down remains a mystery. Fortunately, the project was finished with almost no delay and a beautiful tunnel is now in perfect operation.

1.10 *Awareness and alertness*

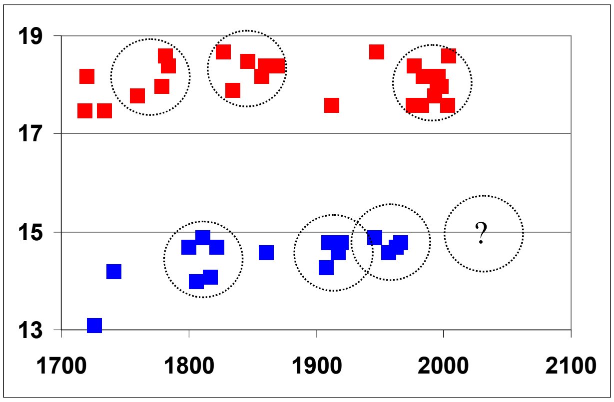


Figure 26. The warmest summers (above 17.5°C) and coldest winters (under 15°C) since 1700, three-month average, 24-hours (source KNMI, De Bilt)

The summer of 2003 was in Europe one of the warmest in 500 years with average summer temperature almost 2 degrees higher than the long term European average over the period 1901-1995. Research at the University of Bern shows that the central part, particularly the Alps, was the warmest with more than 5 degrees above normal. The period 1994 to 2003 was the warmest decennium in 500 years. Is this a climate change? The hottest summers and coldest winters in the last centuries in the Netherlands is shown since the start of official registration in 1706 (Fig.26). The average (three month) summer temperature is 16.6°C. A particular warm period is noticed also 150 years ago. Cold winters seem to occur in between, and apart from the coldest winter ever in 1725 (13.1°C) no trend in climate change is observed, except for a very small rise (only 0.05°/century) of the average winter temperature during cold periods, which is insignificant!

In earlier centuries when most of the meteorological instruments still had to be invented extreme summers can be deducted from diaries, chronicles, archives of old towns, melting of glaciers and crops data (Buisman, 1996). At the end of the 12th to the 14th century summers were warm. This period is called the Climate Optimum. The years 1176-1200 and 1226-1250 belong to the warmest periods. The summers of 1473 and during 1536-1540 were the warmest ever. In Europe, the year 1540 is called the Great Sun Year. These summers lasted nine months! Crops desiccated. The air was thick with ash, dust and smoke from burning fields and woods. Villages and towns, like Breda (1634) and Delft (1536), were destroyed by fires (one could imagine the massive CO_2 emission in the atmosphere). Rivers dried up. In Cologne horses walked across the Rhine and in Paris people crossed the Seine without wetting their feet. The water became polluted, undrinkable. Water mills stopped and there was no bread. Even insects could not find food and attacked the people, who suffered from hunger, dysentery, heart attack and sun stroke. Many farmers in northern countries changed their fields into vineyards. After this period cool summers and severe winters characterized a new climatic period, referred to as the Little Ice Age. Siberian cold crossed Europe. In the winter of 1564-1565 all rivers froze. After burning the trees and peat (turf) people started burning their furniture to stay warm. After these winters massive floods occurred and farmers took their cows into the attics of their houses. From 1625 summers became warmer again.

A study on rain intensity in Belgium over the last 100 years shows that the highly variable nature of rainfall volumes does not show a significant trend, but there is a trend in connecting impervious areas (urbanization) and lower design safety margins which lead to an increase of frequency of flood problems (Vaes et al., 2002). The large variation in temperatures is shown by the world's highest temperature ever measured in El Azizia, Libya, 58°C, and the world's lowest in Vostok, Antarctica, -89°C.

The Intergovernmental Panel on Climate Change (IPCC) states that global surface temperatures have risen 0.6°C over the past 140 years, and that the warm years were 1990, 1995, 1997, 1998 making the last decennium the warmest in the last few centuries. One could wonder about the precision of 0.6°C in the face of such large fluctuations. In 1997 and 1998 the largest floods by intensive rains ever recorded occurred in India, China, Bangladesh, UK, Poland, and hail caused almost the collapse of the entire city of Montreal, with 6 billion Euro damage (only in Montreal). Thousands were killed, millions became homeless, and lack of electricity and drinking water caused illnesses and epidemics. Meteorologists claim El Niño was responsible. It caused much more warmth and vapor in the atmosphere and affected the weather systems all over the world. Why El Niño is more frequent in the last 20 years is not understood. If the climate is a chaotic system, then a small change may have dramatic effect in the long term, but this is still speculation. A small-scale climate change seems to be occurring at the moment, which is not surprising given the earth's history of climate changes over the last 500 years. Similar warm periods are not unusual. A reasonable prediction should be – consider Figure 26 – that before 2100 a colder period may occur.

The Netherlands has a long history of living with water, and a review of major floodings during the last millennium, taken from old chronicles, shows the frequency of disasters (Fockema Andreae, 1953). Over the centuries with increasing land subsidence and land reclamation the dikes increased in number and size, areas became more vulnerable, and water-defense structures became more important.

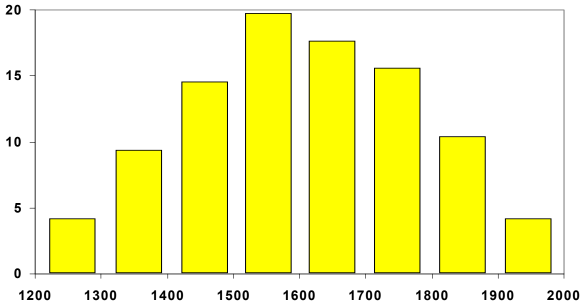


Figure 27. Flood disasters in the Netherlands; frequency per century

After 1600, despite the continuing increase in population, the corner was turned and floods started to be controlled (Fig.27). The present situation shows that the frequency of flooding is low, but the risk (occurrence times consequence) is much larger because the effects to the developed infrastructure in increased population are much more pronounced (Fig.28). When the return period of an event like a hot summer or a major flooding is longer than a human lifetime, people tend to forget the hazard and see new occurrences as unprecedented.

Figure 28. Extreme high river levels in 1995

An 8.9 Magnitude quake in the sea near Banda Aceh in Indonesia (Fig.29) generated a high wall of water that sped across thousands of kilometers of the Indian Ocean, on 26 December 2004. Along the coasts of Thailand, Indonesia, India, Sri Lanka and even north-east Africa more than 300 thousand lives were lost, one million were injured and loss of property was put at 8 billion Euro. The earthquake shows the extreme vulnerability of dense populated coastal zones, even if they appear to be remote from seismic areas. An important issue is the vulnerability of the infrastructure, roads, embankments, railways, pipelines, cables, etc., that prevents immediate adequate rescue and aid from reaching stricken areas after a calamity. Addressing the impact of floods and wave attack is a task for geotechnicians.

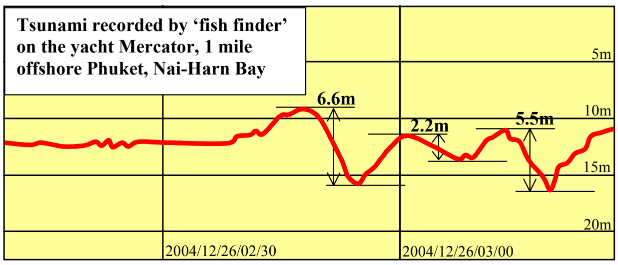


Figure 29a. The tsunami of 26 December 2004 recorded at the yacht Mercator

By pure coincidence, precisely a year before the Asian seaquake, on 26 December 2003, a 6.3 Magnitude quake destroyed the centuries-old city of Bam in Iran killing 30 thousand, injuring 40 thousand and making 75 thousand homeless. These events will never be forgotten by those directly affected, but those responsible for taking appropriate medium-term and long-term measures are often soon distracted by new social, political or economic problems. As society becomes more dependent on its infrastructure for protection, we must work to raise awareness of the benefits our work can provide.

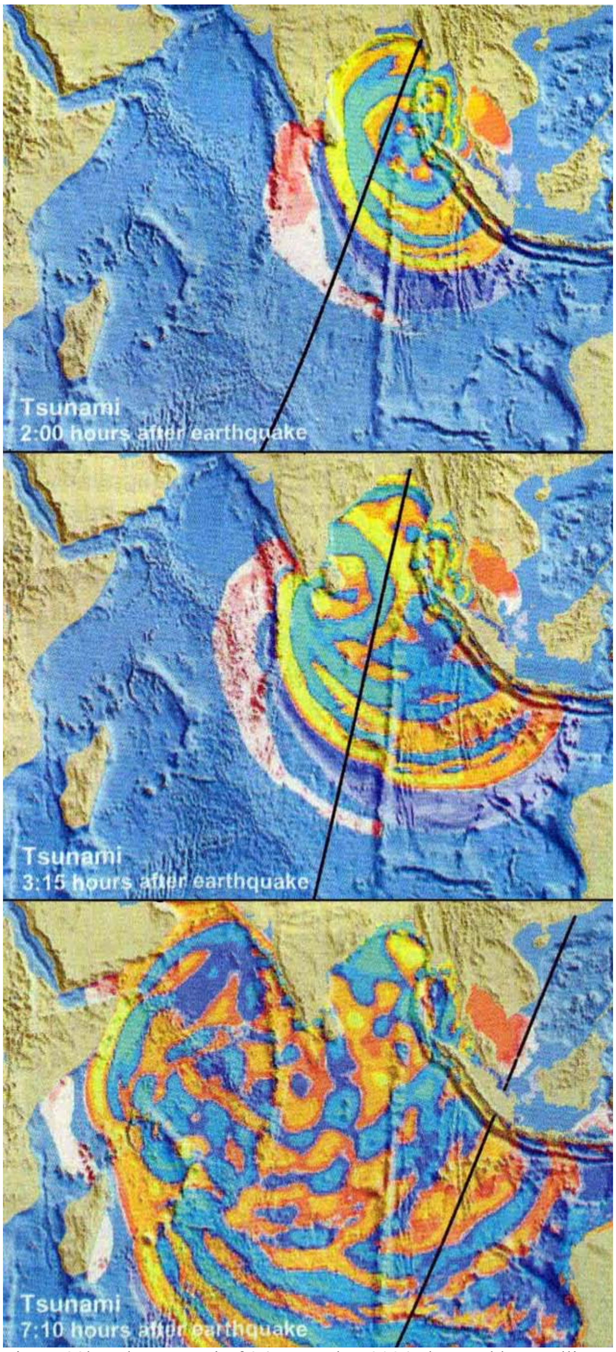


Figure 29b. The tsunami of 26 December 2004 observed by satellites at 2.00, 3.15 and 7.10 hours after the seaquake (Remko Scharroo, NCAA); the lines indicate the path of the satellites; the scan shows the expanding large waves, the water depth and borders of tectonic plates

1.11 *Lessons*

Advances in geotechnics seem to proceed after failures. Insight in soil behavior has been obtained by observation of processes, unseen and not fully understood. Multi-disciplinarity is an essential feature, but it is only effective after the inevitable differences in approach are resolved. Implementation of new insight takes much time and effort. Information, knowledge and experience are not sufficiently transparent, not properly disseminated and updated, and when the return period of an event is longer than a human lifetime, we forget. Experience, awareness and alertness evaporate with time. How can we preserve knowledge? How do we communicate our societal values and fully exploit our expertise?

2 CHARACTERISTICS OF KNOWLEDGE

The new possibilities and changes in information and communications brought out by the global power of ICT have created a new 'art': knowledge management. With the rapidly growing capabilities of information exchange, individuality in teaching is vanishing, education is becoming transparent, and new modes of cooperation are developing. The need for guidance on self-orientation and self-instruction is becoming urgent. Expectations of a new paradise of global information are outrageous. How can we maintain quality in knowledge transfer, how can we give a proper place to experience, how can we prohibit amateurish application of generously offered tools and methods, how can we create engineering awareness? These are important questions. In this paper the fundamentals of knowledge, knowledge values and knowledge transfer, and the aspects where KM and ICT are useful will be outlined.[2]

KM is an area that is enjoying a rapidly growing interest. Knowledge is, beside labor, capital and materials recognized as an essential production factor, and therefore an important focus for management. Companies employ KM to achieve competitive advantages or to shorten the development process of new products. In practice, KM is becoming accepted as an inevitable aspect to improving business management and civil services. In research, KM brought together efforts to make knowledge transparent and enduring. KM has therefore a true potential and should be included in educational curricula as such. Besides, it is obvious that newly established knowledge, itself becoming widely available, offers new ways for innovation and education and training, particularly through ICT.

2.1 *A framework for KM and ICT*

Before being able to understand what KM may imply and what its relation is to ICT, it is important to have a framework of our concepts about knowledge and information. Current ideas appear to fit conveniently into two 'cycles' which are offered here as a basis to evaluate knowledge and communication, one within the discipline of technology and one reflecting society (Fig.30).

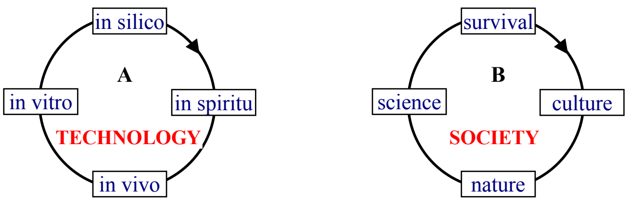


Figure 30. Essential elements of the innovation cycles

In biotechnology it is common to distinguish tests performed in vivo (on life) and in vitro (in laboratory test tubes). With modern developments in genetic technology, a new instrument has recently been added, i.e. intelligent computer handling of immense amounts of data, which is referred here to as 'in silico'. To complete the suite of instruments, a fourth one could be added, our spirit and power of symbolic thought, referred to as 'in spiritu'. Added value will be obtained by the synergy all four. This creates a technology innovation cycle (A).

The question of how humans differ from animals has been the subject of debate since the ancient philosophers. Plato defined it as reason (Latin: ratio). Religion proposed that consciousness, given by God to mankind, was the feature that distinguished us, but doubts about this arose following the developments of the theory of evolution. At present, the advent of symbolic thought and speech are thought to have given rise to development of language. Or put the other way around, language gave way to develop consciousness, since memory and thought are 'phrased' in our mind (Conway et al., 1992). Past and future could be imagined and passed through to new generations, and that made man a formidable competitor (Tettersall, 2000). Language is the carrier of knowledge, enhanced today by the electronic dimension, the Internet and mobile telephone. It guides collective effort towards social adaptation and spiritual meaning, balancing survival, culture, nature and science. It is the domain of a multi-modal exchange of information and communication. This creates an equivalent innovation cycle for society (B), where selection and direction are decided. In this process ICT and the media will play a role, the impact of which will exceed our expectations. The ability to handle information and extract knowledge will become the key to survival. It will give rise to new forms of elitarism. The future is to tele-info, like Seven of Nine of the Borg collective mind in Startrek (Fig.31).

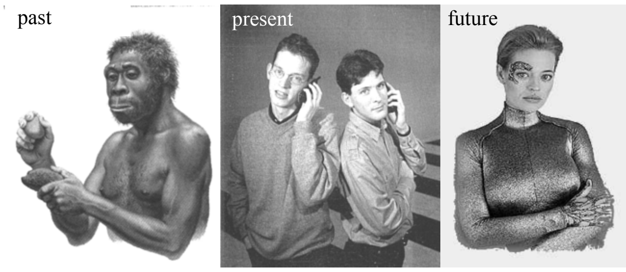


Figure 31. The development of communication; Seven of Nine (right)

2.2 *Knowledge in perspective*

The qualification or quantification of knowledge is not automatic, not a 'linear' process. It is best described by adopting a holistic approach using three modes: facts, experience and wisdom (Hendriks, 1999), which refer to data, meaning and value. This concept is further elaborated by additional perspectives, characterizing knowledge modes in terms of technology and society.

knowledge		*perspectives*		
		feature	*appearance*	*feeling*
mode	***1***	**facts**	**data**	**veni**
	2	**experience**	**meaning**	**vidi**
	3	**wisdom**	**value**	**vici**

knowledge		*perspectives w.r. to innovation cycle A*			
		in vivo	*in vitro*	*in spiritu*	*in silico*
mode	***1***	observation	simulation	objective	Dbase
	2	impact	association	subjective	Ebase
	3	purpose	concept	collective	Vbase

knowledge		*perspectives w.r. to innovation cycle B*			
		science	*survival*	*culture*	*nature*
mode	***1***	trial	chance	emotion	risk
	2	cognition	existence	awareness	system
	3	synthesis	champion	pride	harmony

[2] KM: Knowledge Management
ICT: Information and Communication Technology

2.2.1 *Knowledge mode 1, veni: facts and data*

The collection and organization of facts or data has become very popular given the power of today's computers. Only a decade ago, research involved spending many hours in archives and libraries, but now the Internet and on-line databases have made basic information (facts and data) transparent, more complete and abundant. Data has provided a solid base for improved management and decision-making. However, the overwhelming quantity of data means selection and quality are becoming preeminent (data mining). The key criteria are that facts and data should be objective (without individual interpretation), and describe a reality unconditionally and repeatedly. Facts can be easily archived in databases, when properly designed. Transparency can, in principle, be provided anywhere any time through ICT.

2.2.2 *Knowledge mode 2, vidi: experience and meaning*

In practical situations the context in which data is applied is essential. It makes it meaningful. Data in a context becomes information. A context is a subjective perception of a reality, in which specific interests play a role. Hence, context depends on individual values and personal experience (education and training) and on communication (visualization in media and in public debate). At present, most experience is institutionalized in professional disciplines, where specific values are understood and cherished, and frequently associated with engineering achievements and prior learning. The development of experience through the professional disciplines was the only practical route prior to the arrival of modern computers. Faced with the potential of ITC, we need to question fundamentally how professional values can really benefit KM, or whether new structures will emerge.

2.2.3 *Knowledge mode 3, vici: wisdom and value*

The ultimate purpose of knowledge is to achieve a better world incorporating through wisdom all natural (ecological), emotional (social), spiritual (cultural) and rational (economical) values. Wisdom provides the ethical context for knowledge, balancing all the different pressures in life to achieve harmony. Conflicts between perceptions and interest, prestige and power, are settled by allowing absolute quality, i.e. truth and reality, to attain the highest status and take priority. Questions today are becoming so complex that the best solutions can be achieved only by open-minded cooperation. It requires much effort and pure ambitions.

2.2.4 *ICT-concepts (in silico): Dbase, Ebase and Vbase*

Dbase: Despite the abundance of databases in use everywhere, it is a challenge to truly capture reality in the form of facts and store these as a collective memory, which is designed to be transparent, consistent and extensive. Computer databases will become an inevitable collective human memory expansion. An illustrative example is the enormous development in biotechnology, where genetic modification is made possible by freely sharing plenty of facts. Although ownership of data is still an issue, the data will become free in the coming years; its users will share the cost and effort of data maintenance.

Ebase: A database of information (data in an experience context) is a different concept to a database of facts, as we have in common use today. At present expertise knowledge is stored in handbooks, encyclopedias, lecture books, PhD theses, professional reports, publications, computer programs, etc. How we can store this knowledge in 'collective brains', which are designed to be logical, communicative and, above all, associative, is an important current research topic in geotechnics. How computers can really be of help to extend the human associative mind is still an open question, but it will be solved in future. Already today new communication skills are being developed in electronic workshops and in virtual brainstorming sessions, with interactive decision-making support systems. The concept of expertise-bases (Ebases) will open the way to a free exchange of ideas and expertise. Their users will share the cost of maintenance and updating of corresponding systems and concepts. It will become generally accepted that sharing information improves profitability, competitiveness and value (benefit).

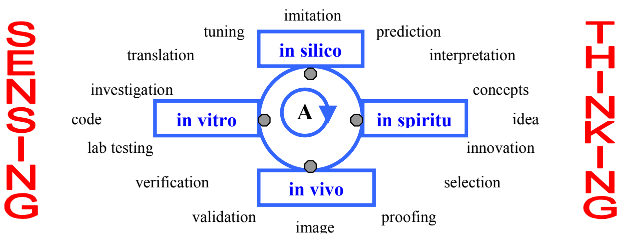
Vbase: At the highest level, we are really discussing how knowledge contributes to quantifying values, of all types: the value of life, value of freedom, value of nature, value of wealth, value of power, value of prosperity, etc. The greatest challenge facing us in KM is to define a socially, culturally, ecologically, economically and scientifically sound and consistent scale of measures, against which aims and strategies can be evaluated. This is a story of economic, social and cultural norms and values, which develop and change with time. Generic achievements in this respect should be collected in transparent documents, its electronic (in silico) manifestation called the Vbase. Spiritual values of various cultures would have a prominent place in such a KM base. Vbases could play the leading role in valuing knowledge development along a way of progress. Such a concept would have important consequences for the future of information, communication, education, learning and training. There is a long way to explore.

2.3 *Knowledge in progress*

How does knowledge develop? There is no single, generally accepted answer, as it depends on the current perception of how one can and should 'know'. This perception depends on which human modus operandi is applied: sensing, thinking or comprehending.

2.3.1 *The technology innovation cycle*

Sensing and thinking are consistent with the, now standard, scientific approach. In this figure the technological innovation cycle (A) is expanded to reflect these modus operandi; based on observation (in vivo), (empirical) rules (in vitro), (theoretical) modeling (in silico) and hypotheses (in spiritu).



In this technological innovation cycle validated knowledge is anchored in tools (SENSING): calculation models, codes of practice, and testing/monitoring facilities, and in expertise (THINKING): scientific publications, education curricula and engineering experience. That this innovation circle is fruitful can be demonstrated by many examples, two of which are famous and described here. One starts with thinking and one with sensing.

The theory of curved spaces and surfaces was developed by Riemann in the 19th century as a piece of purely abstract mathematics, without expectation that it would be relevant to the real world, yet became in 1913 crucial to Grossmann and Einstein's idea of expressing gravitational forces in terms of space-time warping to mass and energy. The observation in 1919 by a British expedition to West Africa of the slight shift in the position of stars near the sun during an eclipse (Fig.32) predicted by this theory, was therefore a spectacular proof of the general relativity theory (Hawking, 1999).

Advanced complex numerical calculations around 1955, with the then latest computer code (HAMPcode, NASA) on what might happen to the earth when subjected to a nuclear bomb, predicted a deep crater with an exudation, a small upright cone precisely in its center. At first, it was assumed a persistent numerical error, but it appeared after thorough investigation to be a true physical phenomenon related to dynamic 3D compression in the center that, after the explosion, was released as an extruding outcrop. Independent validation was found by close observation of moon craters with enormous telescopes. It showed a mountain in the center (Fig.32) of every crater, created by a meteor collision.

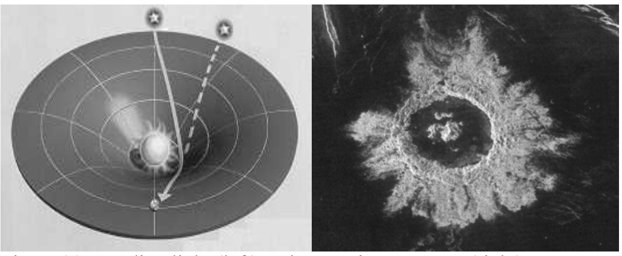
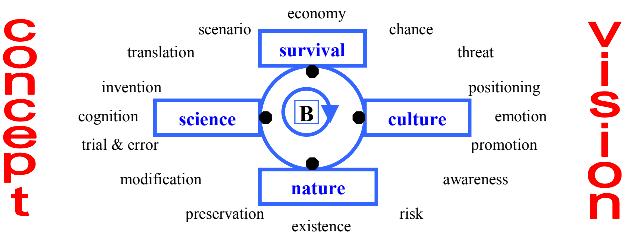


Figure 32. Bending light (left) and mysterious outcrop (right).

2.3.2 *The societal innovation cycle*

Nowadays, social debate on sustainable development has also entered the technological innovation cycle, exposing the value of knowledge to its cultural, ecological and economic relevance. These three aspects comply with the prepositions made by the World Bank in its policy for development investments. They are to some extent exchangeable and mutually dependent, but not additive. Since the means for knowledge generation depend on such policies, the discussion on knowledge attains new impetus and enters a new phase when we discuss the interrelations between the three qualifying aspects and their quantification. It is here that the role of KM becomes significant.

In this debate, however, the concept of technical science itself as an independent intrinsic characteristic and an essential element of our prosperity is not widely accepted. This is probably a reaction to the period of technocracy that started in 1850 and continued until long after World War II. But it should not be denied that technical science plays an equally important role in knowledge development. By considering a second innovation cycle: the societal innovation cycle (B), in which science is retained in the cycle of societal innovation, it is possible to extend the present day social debate about CONCEPT and VISION to provide a context for what is important in our existence.



2.3.3 *The way of progress*

As technical knowledge develops according to the technical innovation cycle, actual improvement in society proceeds through continuous interaction of the technological innovation cycle A with the societal innovation cycle B, creating the potential for progress. As these cycles take place, discrete steps towards progress can take place (Fig.33).

Integrated evaluation and decision making gained sharp attention in the Netherlands when in 1993 a national committee for underground transportation infrastructure presented its results. A complete vision had been elaborated by six working groups covering fields of legislation, economics, techniques, environment, research and decision support; as such, in full accordance with the societal innovation cycle (B). The studies were based on several realistic cases of intended large transportation facilities. This approach was further developed into an integral decision support computer system for industrial underground space development (Nieuwenhuis, 2000).

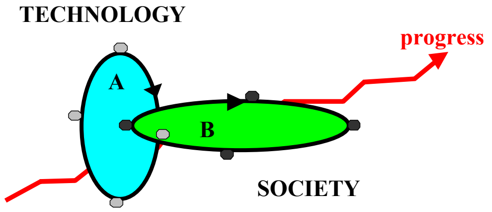
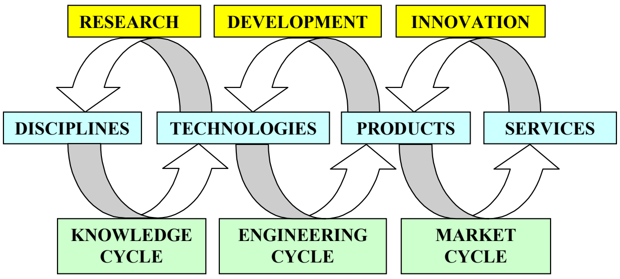


Figure 33. Innovation cycles lead to steps in progress (roadmap).

Beside decision making, productivity is another key issue in the route to progress. How can a knowledge driven market develop (Krebs, 2004)? Society and private clients do not any longer accept the attitude and the processes of the construction industries. Up till now maintaining short-term profit levels has been the reason to continue working in the traditional way. With new legislation to protect workers, clients and the environment it will gradually become impossible to continue in this manner. Future competitiveness depends on the ability to understand the client's needs and to learn from new entrants. Their approach may inspire a radical change of existing practices (Scheublin, 2004).



In the Cyclic Innovation Model (Berkhout, 2000) the linkage between the steps in the route to progress is recognized and related to the roles of different actors, universities, technology institutes and industry. A distinction is made between the knowledge cycle (research), the engineering cycle (development) and the market cycle (innovation). In the knowledge cycle money is invested and in the market cycle money is earned. The intracyclic and intercyclic combination involves both a distribution process (one-to-many) and a collection process (many-to-one), supported by active individual service in all sectors. This multi-dimensional knowledge-network interplay is essential in modern technological innovation. A network grows exponentially with the number of users. Hence, it will remain functional, if it can keep up with its growth. Enhancement and acceleration are being provided by KM and ICT, and these are, according to Berkhout, the new drivers of economy. In the building and construction sector, where more that 90% of enterprises are SMEs (Small and Medium Enterprises), innovation is perceived as a high risk and cost endeavor associated with uncertainty and caution. To enhance innovation requires special attention and education (Freitas et al., 2004). For drastic improvement several serious thresholds have to be overcome.

2.4 *The value of knowledge*

The value of knowledge is determined by the appreciation of its quality. Discussions about quality reveal a serious discrepancy between the basic aims of the academic world and the practical world, between the values of fundamental knowledge generation and practical knowledge innovation, between creativity in depth and in width. In fact, this discrepancy should create no distance, since both worlds are relevant and money or effort can only be spent once. By stimulation of profitability, applicability and transparency in fundamental innovation on the one hand, and stimulation of the state of the art, quality and feed back of practical innovation on the other hand the differences in appreciation of quality become less prominent. Quality of knowledge can be visualized from a scientific and a practical perspective.

quality item	*scientific*	*practical*
successful	**yes**	**yes**
pleasant	**yes**	**yes**
durable	**yes**	**yes**
strategic	**yes**	**yes**
excellent	**yes**	**no**
true	**yes**	**no**
fundamental	**yes**	**no**
efficient	**no**	**yes**
competitive	**no**	**yes**
profitable	**no**	**yes**

The desire for quality in scientific and technological research and development is a major point of attention in a quality assurance policy, either in the academic world or in the world of practice. It deals with awareness of a harmonic blend of all aspects related to scientific level and social relevance in education curricula and in practical codes. In the Netherlands this quality is confirmed by a generally accepted system of procedures, instruments and criteria, although social values are a permanent topic of discussion (Spaapen, 1991).

As for fundamental knowledge innovation the prime aim is to know how innovation is done and how the quality is measured by past performance, so it is for practical knowledge innovation to make sure that it is done and the quality is shown in performance. To this aspect there is some ambivalence in promoting knowledge. An opportunistic distinction can be made between "don't think, but do" and "first think, than do". We stimulate this ourselves: answering a practical question, "is it possible?" with, "Yes, everything is possible!" and to a fundamental question, "do we know?" answering "No, much we don't really understand!" What counts is the success factor. Young people are looking for activities that promise competence, recognition and personal success, whether it requires effort and courage or promises status and wealth. The value of knowledge innovation, which is after all a work of the mind, depends much on this drive. It plays an important role in the format of ICT as a support for education and training.

3 COMMUNICATION (knowledge transfer)

According to Shapin and Schaffer (1989) knowing is equal to giving trust. People usually tend to consider new technologies as a threat, a new phenomenon against which they are powerless. In reality science and society are strongly interwoven. New inventions influence society and vice versa, acceptance of technology is a typical social process.

In the 17th century a debate between Boyle and Hobbes gave the onset of our scientific approach today. Hobbes proposed that real knowledge can be obtained by pure reasoning, and experiments are unreliable and not controllable. Boyle said that knowledge could be collected on the basis of experiments; it is continuously modified; knowledge is not absolute but based on consensus in an intellectual community. Boyle won.

However, the philosophy of Hobbes is interesting. Who composes the intellectual community? Experts are usually mistrusted. Society asks experts for proof. In fact, there is continuous pressure between egalitarism and elitarism. On the one side, one is democratic and find that everybody has equal right to speak, and on the other side, one lives in a world, which is strongly dominated by experts. What we know about the world is not based on personal experience but on the testimonies of experts.

The question is how these testimonies are communicated and whether we can trust them. Public and political acceptance of experts' findings is sometimes guided by peculiar visions. In the 19th century the conservative Prime Minister Lord Salisbury welcomed the new system of electric lighting, as he believed that it would destroy cities. By distributing electricity all over the world rural life in a pastoral world would return. The socialists (Lenin) welcomed electric power as it would allow rational planning and centralize the economy.

Today the world is even more dependent on the statements of scientists and experts and the call for proof and control in knowledgeable societies for acceptance of new technologies becomes louder. Inspiring trust by communication and sharing in and beyond the field of our profession become inevitable for progress. Proper dissemination of knowledge is crucial to our way of life.

In the previous section knowledge was the object. In this part the persons involved are the object, as it is essential that knowledge be communicated, at least in selected groups. Therefore, education and training are a permanent part of life and they deserve continuous attention.

Knowledge transfer takes place in many forms and ways. It is the transfer of knowledge from a provider to a receiver, by subject or object-organized information, in terms of orally presented ideas or written instructions, implicit and/or explicit.

3.1 *Forms of communication*

A general view of knowledge transfer based on this approach is shown in the following table (Nanaka & Takeuchi, 1995).

receiver \ *provider*	*implicit*	*explicit*
implicit	11. **socialization**	12. **internalization**
explicit	21. **externalization**	22. **combination**

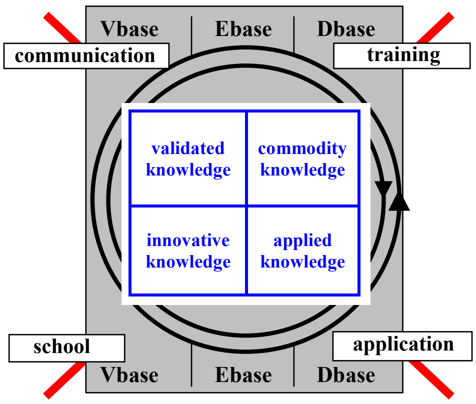
Implicit means inherent, suggested or being understood while explicit means definite or distinctly and clearly expressed. In communication and information exchange it is therefore obvious to connect implicit to mind (expressed, explained, and subjective) and explicit to word (written, defined and objective). Where minds interfere in consensus socialization is created (11). Words may be combined to define commitment (22). Self-education is when words are used to enter the mind, i.e. by instruction (12). When the mind is used to create words, it is education, i.e. expressing the meaning clearly and understandably. This deduction is helpful in understanding means of information and communication, and hence to give direction and proper expectation from the outrageous developments in ICT.

Elaboration of other aspects and realizations yields a more complete view on the process of knowledge transfer is shown in the next scheme, where most of the usual terms and definitions are collected. In every quadrant the role of provider and receiver is different; object oriented (pull) and provider and receiver being at equal level in sharing and policy making (11) or in joining and doing (22), and discipline oriented (push) and provider and receiver being at unequal level in teaching and learning (21) or studying and coaching (12).

A new and promising approach (from field of accountancy and information systems) is to extracting information from unstructured documents based on an application ontology that describes a domain of interest (Embley et al., 1998). Ontology is a branch of philosophy that attempts to model things as they exist. It is particularly appropriate for modeling objects including their relationships and properties from unstructured documents for different application domains and reformulate it as a structured document.

SOURCES OF KNOWLEDGE	*Implicit knowledge*	*Explicit knowledge*	
	Mental database (*efficiency*) → 75% (*transfer time*) → long	Written database 20% moderate	Numerical database 5% short
ICT	Vbase	Ebase	Dbase
IMPLEMENTING KNOWLEDGE	*Ontology* A way of life	*Epistemology* Craftmanship	
Implicit knowledge	**11** *Mind ↔ Mind* Evaluation communication direction and selection wisdom & balance **PULL** *Socialisation*	**12** *Mind ← Word* Excercise training information to knowledge study & coaching **PUSH** *Internalisation*	
Explicit knowledge	**21** *Word ← Mind* Expertise teaching the art knowledge to information research & adventure **PUSH** *Externalisation*	**22** *Word ↔ Word* Experience application data and information practice & profit **PULL** *Combination*	

In the following scheme, based on a similar approach, the type of knowledge (validated, innovative, applied and commodity knowledge), the place of action (practice and school) and the transfer itself (communication and information) is shown. One may distinguish a diagonal of education and training, and a diagonal of communication and application. Furthermore, the previously suggested ICT-tools Dbase, Ebase and Vbase are incorporated where they can be of support in the transfer. Finally, in the graph two circles are shown. The clock-wise circle represents the growth of individual knowledge, i.e. a line of personal development. The counter clock-wise shows the dissemination of knowledge, i.e. a line of transfer.



The purpose of this diadram is to clarify the processes in which knowledge is an issue, and to recognize the corresponding context. Is exchange of knowledge (communication) achieved by exchanging opinions, by teaching, by reading and study, or by legislation, regulations and guidelines? This distinction makes it easier to understand the relations and interactions in communication, what KM means, and to what extent ICT-tools can provide support. The schemes could assist in defining the requirements and specifications for ICT tools to be developed in their specific contexts.

3.2 *The impact of KM and ICT in engineering practice*

Education and training does not stop with a school diploma. Postgraduate training and knowledge transfer is important and will become more and more essential to maintain the standards of living and working. In this context, the art of interdisciplinary communication is indispensable. Problems become more and more complex, and society requires clever, multi-functional solutions. Ways of cooperation and the line of process are changing, sometimes drastically and faster than anticipated. Time needed for debate and decision-making exceeds the time allowed for production and realization. There are usually opposing interests and sectors of society have narrow interests: industry is interested only in competition, politics only in campaigns, and science only in competence. All are willing to share their efforts in improving the process only where it is aimed at lesser price. Globalization stimulates individualization. Individualization leads to risk awareness. However, the quality of life and preservation of cultural and natural heritage at risk is a collective responsibility. Risk consciousness and a dedication to collective goals will achieve priority over partial interests if people are made aware (Fig.34).

Figure 34. Sharing risk consciousness in spiritual awareness

We need a framework for sharing the risks facing society. In this context KM, which is the art of managing relations between knowledge carriers and ICT, which provides the information in suitable form on these carriers, will help to give the required impetus. This is a great challenge.

It seems that mankind is becoming aware that focus on the development of the left-hand side of the brain (reason, perception) should be brought in balance with the development of the right-hand side of the brain (emotion, feelings). A confrontation in the societal innovation cycle is logical, because the question: “Is it possible?”, which is essential to the technical innovation cycle, is counteracted in the societal innovation cycle by the retort: “Is it acceptable?” Here, the art of KM in dealing with the interaction between the technical and economic feasibility, social admissibility and communicative and persuasive skills is highly relevant.

In this confrontation one should realize which aspect is in focus in the discussion about appreciating knowledge. In the societal innovation cycle, innovation is subjected to a power game between political issues and scientific topics, between life and spirit. The correct knowledge modes and social norms must be addressed. The professions involved should pay particular attention to expressing themselves clearly and to being well understood. It is in this activity that ICT can support the evaluation and optimization of information and communication, education and training, as well cooperation and competition. Our life is changing continuously, and so our means to survive.

As societies develop in prosperity, it is worthwhile not to forget, as history teaches, that too much attention to materialism, in the name of quality, is the onset of decay (Le Pair, 2000). The quality of all aspects in the societal innovation cycle deserves therefore equal attention.

4 CONTEXTUALIZATION

Science and technology is not any longer separated from society. Our way of life is dominated by science and technology, and societal and technological development have become strongly interconnected. Innovations require contextualization.

4.1 *Trueness in geotechnical sciences*

Once a professor stated in one of his lectures: "Most probably, 50% of what I will tell you has never been true, is not valid now or will appear to be false. Since I do not know which half this is, I'll tell you all." According to Dyks, engineering is the art of modeling materials we do not wholly understand, into shapes we cannot precisely analyze so as to withstand forces we cannot properly assess, in such a way the public has no reason to suspect the extend of our ignorance.

Philosopher Karl Popper, one of the leading science philosophers of the 20th century, explains in his autobiography *Unended Quest Popper* one of his striking ideas that absolutely correct knowledge does not exist and that science progresses by trial and error, by hypothesis and falsification. The best scientific theory is one that is subjective to challenge but continues to hold out. No one knows if tomorrow yet another theory will appear to contradict it. The idea that scientific knowledge develops by collection of observations and facts leading to a general conclusion (induction) and that a scientist should look to confirmation of his theory (verification) does not hold. According to Popper, a scientist should work deductively starting from a problem definition and he should look for falsifications of his theories.

In the field of geotechnics, which is largely a field of uncertainty and empiricism, Popper's philosophy holds by nature. Our comprehension in soil behavior is being falsified frequently and subsequently improved by events of failure. A modern way of accounting for uncertainty in geotechnics is by risk analysis, which is, in fact, a suitable method of falsification. In this attempt we should be looking for safe uncertainty instead of uncertain safety. We need to be confident in our prediction and at the same time suspicious about their large margins. For non-professionals this paradox may render the advice of a geotechnical expert seemingly unreliable. What is required is a window of reality bounded by estimated borders of true expectations. We need to explain and communicate this trueness of geotechnics.

4.2 *Anchoring progress in the past and the future*

The course of progress as described in the previous chapter involves innovation and development within the discipline, i.e. the content, and growth in its environment, i.e. the context. The anchor for this approach is the actual societal and scientific position of the profession.

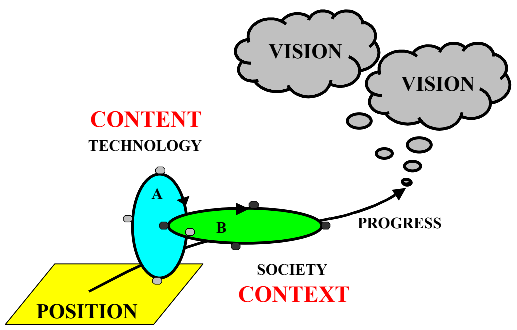


Figure 35. Progress linked to position and vision (Wentink, 2000)

The focus of the approach should be a vision at a foreseeable horizon, a vision that is supported in a wider context, based on firm grounds and accepted by a majority of shareholders (Fig.35). In fact, it is a dynamic process, as visions change under changing economic, cultural and natural conditions.

With the aid of a professional marketing consultant the Dutch national geotechnical institute GeoDelft undertook in 2002 a self-evaluation initiative with a focus on the geotechnical professions' image amongst a wide group of clients, including governmental and regional authorities, contractors and consultancy bureaus, universities and technology institutes. This action was necessary to define our new strategy in a changing society. To streamline this process the following specific roles were defined:

- Executor/facilitator of R&D (knowledge development);
- Industry advisor (building practice);
- Strategic advisor (risk management);
- Institutional advisor (governmental task).

GeoDelft's activities, as a national technology centre, were grouped into the so-called 7 Geo-concepts:

1. GeoVision: creating a vision of societal developments for which geotechnics is relevant, valuable for policy makers;
2. GeoCheck: a generally accepted quality mark assigned when proper use has been made of risk assessment concerning geotechnical aspects of a project or process, valuable for strategy makers;
3. GeoBrain: providing relevant knowledge, a synergy of expertise, experience and predictions, in a clear and structured way, valuable for decision makers;
4. GeoSystems: a software toolbox with prediction and visualization tools, representing an 'expert on site', valuable for project managers;
5. GeoLab: an accessible experimental environment with sophisticated field, lab and model facilities and dedicated expertise, valuable for innovators;
6. GeoRisk: a risk analysis system supporting risk assessment in every part of a process chain, valuable for risk managers;
7. GeoDelft Academy: dedicated education for the other Geo-concepts by workshops, in-house and in-company training, valuable for knowledge transfer.

The outcome of the inquiry resulted in a clear and valuable picture of strong and weak points and gave insight to realistic opportunities and threats. The result was supported by a wide group of societal players and has become the basis of a new strategy for the institute for the next ten years.

The value of a shared vision is not its validity but rather that it helps to set out the roadmap, the route towards progress, by setting priorities and goals in a limited time frame with the commitment of those involved. In this context it is very much the art to develop generic, flexible and transparent concepts and tools by which continuity in knowledge and connectivity of experience are guaranteed. Contextualization is therefore related to the technological innovation cycle (A) concerning transparency in attitudes, methods and tools in the profession itself as well as to the societal innovation cycle (B) concerning transparency and added value in society.

4.3 *A new Agora*

Today, with society swamped by science and technology, other new influences have started to infiltrate the scientific world. Previously, scientific development was based on differentiation and on independent autonomous practice focused on the production of genuine knowledge, and was not influenced by economic and political interests. This independence was believed to be essential to achieve the task set by society: to contribute to the process of economic, political and cultural rationalization. Scientific progress was seen as the motor of societal progress. This situation, referred to as the *mode 1* science and society (Nowotny et al. 2001), is typified by segregation and differentiation in subsystems, such as science, politics, economy, etc., where science is a pure discipline, i.e. a collection of generally accepted lemma's, theories and methods that form a guideline for research and development. The added value to society was just a matter of application.

The "scientification" of society evoked a new reaction, which after Nowotny results in a *mode 2* society and science, is typified by integration of subsystems, a weaving together of state, market, politics, culture and science. Institutional borders become blurred: the knowledge and information society, where science and technology have penetrated into the hearts of economy, politics and culture. The trend 'innovation everywhere' is a striking proof of this process. In all societal questions, scientific and technological developments have become crucial. In fact, many of these questions are also a result of these developments, like environmental pollution, medical-ethical questions, mobility problems, globalization, and even modern warfare and terrorism, since they are steeped in the results of scientific and technological research. Hence, science and technology also create new uncertainties and risks: the risk society (Beck, 1992). Ironically, the solution for these problems can only be found through more scientific research and technologic development.

Science is no longer independent. Science and society have become "co-evolutionary". Content and context cannot be separated (Bijker and Law, 1992). Because science and technology are deeply rooted in society, societal questions and doubts are an integral part of scientific research and technological development.

The change in the relation between science and society has far reaching consequences for its functioning, its image and its justification. Society has had a strong voice in science policy, not only in the application but also in cultural and normative implications. Due to this contextualization new forms of knowledge and knowledge organization have arisen, more complex, fragmented and time and place dependent. Characterized by inter-disciplinarity and problem orientation this has involved a hybrid and changing configuration of actors, with increasing uncertainties. Themes, goals, approaches and criteria for evaluation are from the outset, a subject of debate between industrial players, politicians, researchers, societal organizations and interested amateurs. The classic evaluation of knowledge generation in terms of accurateness, objectivity and truth now includes social and practical robustness. Decisions are made in this new "Agora" where the context is defined, where public and private interests meet, where different opinions emerge, and where – if they want to play their role – researchers have to raise their voice.

Technician's world	Manager's world
Think in terms of risks, threats, problems	Thinks in terms of chances, opportunities
Wants to control risks	Wants to avoid risks
Deals with rational processes	Deals with non-rational processes
Operates integrally to optimize	Operates stepwise reacting to changes
Wants to develop arguments (fundamental, justified)	Wants to realize and score, flexible, dynamic
Sees managers as slow and inert	Sees technicians as slow and inert

What language we must speak? For making others listen to our arguments it is essential to know the wishes and concerns of other actors, and to present the argument in appropriate terms. Politicians are not much interested in cost reduction, and the industry does not need perfection. The differences between managers (administrators) and technicians became evident in a recent workshop on urban renovation (Karstens et al., 2003). A technician is an improver: he sees risks and desires to contribute to a solution. A manager is an entrepreneur who wants to score and he sees opportunities. Technicians believe the approach would benefit from integral risk management, but managers do not want to hear about risk. Risk – in their eyes – provides ammunition for the opposition and causes stagnation. They like to avoid discussion about risk, particularly if it is outside their responsibility, even if this attitude involves more costs. Some remarkable differences were noticed in their attitudes to the problem (see Table above).

The manager's world dominates in society. A planning and decision-making process is usually chaotic and fickle; it is important that projects go on. Managers usually see experts as people with a hammer looking for a nail, with little idea of the actual policy. What moves different actors is shown in the following table.

Actor	Desire	Concern
POLITICIANS	POWER	VOTES
AUTHORITIES	CONTROL	CAREFULNESS
INDUSTRY	PROFIT	COMPETITION
MEDIA	SCANDAL	NEWS
SCIENTIST	PERFECTION	IGNORANCE
PUBLIC	SECURITY	COMFORT
NATURE	EXISTENCE	EXTINCTION

To get attention we must speak the corresponding language. As technicians, if we express our added value in the correct wording, in a context that is easily understood, our position will gain strength and the value it deserves.

Societal development is a global process. In different countries the stage is different. At present, multinationals and politicians seem to be dominant, waiting for the response of a new multi-national society. The economization (science parks, private-public liaisons, knowledge consultant centers, science-industry partnerships) is at odds with the democratization of scientific research and technologic development. Economic and political forces are threatening to undermine integrity. In some cases data is being manipulated for partisan purposes, or companies fund independent scientific studies to influence public opinion.

In the end, democratization of science is a positive move, as the quality of knowledge will increase and expertise will become transparent and sustainable. It will provide answers to the new problems of the knowledge and risk society.

How can we conquer knowledge barriers, how can we make science and technology transparent, and how can we reach societal robustness without loss of quality and reliability? After all, we must realize that we live in a world where money rules though its power remains largely unseen. The world is a casino where some 2000 billion Euro changes ownership daily of which 98% is pure speculation, i.e. money not earned by service or goods. The consequence is war, poverty, pollution and speed (Lietaer, 1999). The strongest role is, and probably will be, played by the media. Damage, failure and corruption are magnified in mass media, as in a public trial, producing a negative image. But the media are also the perfect carrier for positive achievements and messages. For weeks the astonishing possibilities of biotechnology in geotechnics attracted media attention, in newspapers, television and magazines, in the Netherlands. People found it exciting, and readiness to invest increased.

4.4 *Position*

In his keynote address "Common Ground" at GeoEng2000 Morgenstern (2001) highlighted the nature of geotechnical engineering,

Geotechnical Engineering

objects	*skills*
Structural Support Systems	Structural Mechanics Hydrology Geology
Fluid Control Systems	Rock Mechanics Soil Mechanics Public Policy Contract Law
Underground Geostructures	Risk Management Mechanical Engineering Construction
Surface Geostructures	Ground Movements Site Exploration Geochemistry
Ground Improvement	Material Numerical Analysis Continuum Mechanics

and he considered the basic questions.

- Who are we?
- What do we do?
- How did we come into being?
- What have been our accomplishments?
- How do we add value now in engineering practice?
- What special problems confront us?
- Do we need change or is it business as usual?

Morgenstern states, while considering soil mechanics, rock mechanics and engineering geology, that notwithstanding memorable achievements in the past and exciting new developments now the way in which geotechnical engineering adds value is not well understood, recognized and rewarded. He shows the wide variety of skills in our profession and emphasized that uncertainty is chronic in geotechnical practice; risk must be managed.

The professions struggles with inadequate performance, inadequate compensation and inadequate recognition and, according to Morgenstern, value-added contributions arise from an integrated perspective rather than from specific skills. He proposed that a new International Geotechnical Union composed of the ISSMGE, ISRM and IAEG could support such a role.

In 2002 ISSMGE, ISMR and IAEG formed a Joint European Working Group on the professional competencies of engineering geologists and geotechnical engineers for the definition of professional tasks, responsibilities and co-operation in ground engineering. They recently reported that notwithstanding the need for a better understanding between soil and rock mechanics and geology Terzaghi did not reach a firm conclusion, even in 1963: "No hope to finish the book on engineering geology, because this subject is, for the time being, too much in a state of flux and my time is running out". Also the Working Group could not establish strict borders between the different ground engineering aspects, and concluded that required professional competencies should be defined project-wise, dependent on the regulations of Eurocode 7 (geotechnical category):

Geotechnical Category	Cooperation geotechnics and eng geologist
G1: simple project	Optional
G2: average project	Advised
G3: complex project	Essential

Discussion and production of the European Standards (Eurocodes) was the first opportunity to gather geotechnical experts from all European countries around the same table with the specific objective of harmonization of European construction practice. In the case of geotechnical construction, full convergence could not be obtained on many important points (design methods, safety factors) so that the Eurocode still remains as a pre-standard, implementation details being fixed by expected National Annexes. As a result, standardization in this field is far behind developments in the US, and forms a barrier to competitiveness of European contractors on the international market. Developing new design and construction methods and encouraging research at European level will give an important leverage to overcome this difficulty. This is one of the primary objectives of the network project, GeoTechNet (Steedman and Barends, 2003).

These previously mentioned activities are examples of self-reflection, remaining within the discipline. How do others look at us? In this and the next section, I describe some activities that step outside the borders of our own territory.

The ISSMGE groups about 70 national member societies of which 30 come from European countries. Membership is on personal basis, and the majority is from geotechnical research and knowledge institutes. Its main business is the organization of conferences. Technical committees cover most aspects of geotechnics. Their work is concentrated on the promotion of knowledge, exchange of state of the art and expertise. The ISSMGE does not specifically address RTD objectives or networking activities.

It is recognized that national geotechnical research institutes individually do not possess the size and means to take substantial steps towards achieving a clear socially accepted profile – though in many countries the societal imbedding of geotechnical research and knowledge strategies are being developed (Holm et al., 2004; Bell et al., 2004) – a significant improvement in the optimization of geotechnical aspects of civil construction works and a substantial reduction of risks and unforeseen costs can be achieved by joining efforts. ELGIP[3], the European Large Geotechnical Institutes Platform, was therefore established in 2002 to provide an operational framework for the promotion and integration of expertise, experience and efficiency within a common policy for research, development and innovation (Barends and Steedman, 2004). ELGIP intends to take actively part in existing European organizations. At present, it is an active member of ECCREDI[4], and has taken a leading role in the initiative to establish a European Technology Platform for the construction sector. In ECCREDI, which includes the full cross section of the construction sector, the role and image of geotechnics is being firmly argued, and it provides a portal to other societal players and international research policy.

The problem of low societal awareness is also common in other branches of the construction sector. In terms of its importance to society, the European construction sector has an annual turnover of 910 billion Euro (about 10% of the EU GDP) and

[3] ELGIP (www.elgip.org) is the European Large Geotechnical Institutes Platform, its members are: Belgium (BBRI, Brussel), Czech Republic (Technical University Prague), France (LCPC, Paris), Germany (Technical University Darmstadt), Netherlands (GeoDelft), Norway (NGI, Oslo), Portugal (LNEC, Lisbon (invited)), Russia (NIIOSP, Moscow (invited)), Spain (CEDEX, Madrid), Sweden (SGI, Stockholm), UK(Cambridge University).

[4] ECCREDI (www.eccredi.org) is the European Council for Construction Research, Development and Innovation; ECCREDI members are: ACE (Architects' Council of Europe), CEBC (Consortium of European Building Control), CEMBUREAU (The European Cement Association), CEPMC (Council of European Producers of Materials for Construction), EAPA (European Asphalt Pavement Association), ECBP (European Council for Building Professionals), ECCE (European Council of Civil Engineers), ECCS (European Convention for Constructional Steelwork), EFCA (European Federation of Engineering Consultancy Associations), ELGIP (European Platform of Large Geotechnical Institutes), ENBRI (European Network for Building Research Institutes), ENCORD (The European Network of Construction Companies for Research & Development), EOTA (European Organisation for Technical Approvals), FEHRL (Forum of European National Highway Engineering Consultancy Associations), FIEC (European Construction Industry Federation).

provides work for 12 million employees directly (in 25 million enterprises, of which 95% are SMEs) and another 13 million employees indirectly, making the sector one of the most important economically (source: ENCORD). Awareness within society of the scale and importance of the sector is low. In particular, the role of the geotechnical profession is hardly recognized, even within the construction sector, despite the fact that construction of buildings, transportation infrastructure, environmental and hazard protection works involve a significant geotechnical element and that ground engineering is often a major element of the uncertainty or risk in any construction project. At the level of national or European RTD programs, research investment in geotechnics is small compared to the potential benefits. The situation needs a change, if society is to see the benefits of our advancing insight in the field.

Through its website connecting relevant other sites and developing new carriers for knowledge integration ELGIP will evolve into a self-standing virtual centre of knowledge to help and promote the development of information systems, design tools, test laboratories, model facilities and related expertise with the emphasis on mutual complementarities, in a European context. Recently, it supported the foundation of YELGIP, young ELGIP, to provide a forum where young promising researchers can be trained in international and inter-disciplinary networking.

ELGIP has established close links with the EU-funded GeoTechNet project and is discussing how the substantial work that has been completed can be carried forward. Similarly, ELGIP is collaborating with E-CORE, the European Construction Research Network project, which is preparing a vision and strategy for the wider construction sector. These collaborations and contacts are considered to be essential to create a voice for the geotechnical research communities that is active across the continent. At the occasion of the 16^{th} ICSMGE at Osaka, ELGIP will meet a group of Asian Geotechnical Institutes[5] and they will exchange visions on strategic actions concerning research and business.

4.5 *Vision*

It goes beyond the objectives of a Terzaghi Oration to present here a vision for the geotechnical society. But what can be shown is one of the many processes dealing with vision development that is taking place at the time of writing this paper.

Over the past two years, the European Construction Research Network (E-CORE) has developed a strategy for RTD for the construction industry: a manuscript for raising awareness of issues which will shape the future and a guideline to actions, so that directions of change can be amended as new aspects become significant. Starting with the well-known present-day characteristics of the European construction sector, i.e. fragmentation, no focus on end-users, local environmental impact, highly regulated, slow to innovate, lack of performance indicators, process based competition, high resource usage, high labor intensity and poor dialogue with society, E-CORE recognized five major viewpoints:

- meeting users requirements;
- meeting environmental demands;
- changing construction process;
- new materials and technologies;
- enhancing construction employment.

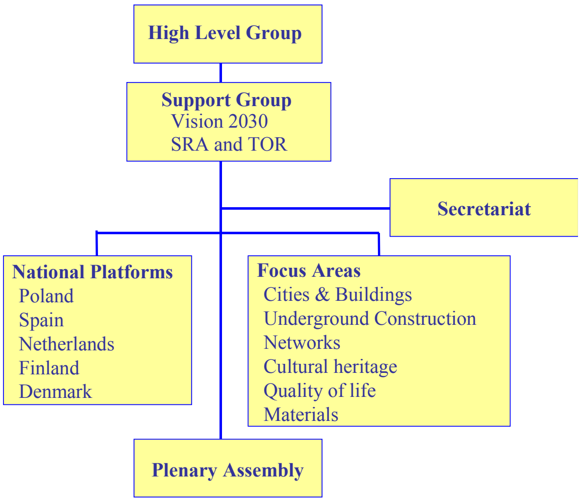
These viewpoints provide routes for progress towards top priority goals:

- a value focused industry;
- a socially responsible industry;
- an innovative learning industry;
- a valued industry.

These viewpoints make the sector sustainable and knowledge based. In a comprehensive report these topics have been worked out into operational aspects and concepts (E-CORE, 2005), addressing the following issues:

European challenges	**Global competition**	**Sustainable development**
Aging population	New technologies	Pollution
Health	New products	Water demand
Safety & Security	Low wages	Cost of energy
Growth & Jobs		Climate change

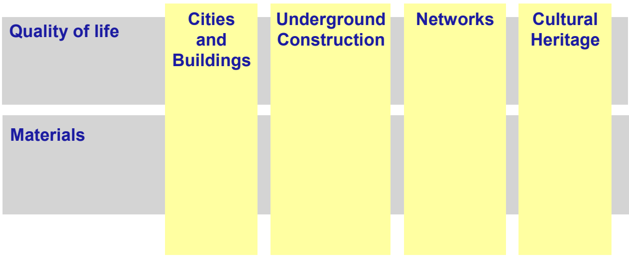
A new instrument in the European Research Area is an ETP (European Technology Platform). As member of ELGIP and ECCREDI, I have been involved in the initiation of such a platform for the building and construction sector, called the ECTP, which will act as an umbrella for innovation in the sector and is led by industry. In parallel, other initiatives have been launched at national level, i.e. the establishment of national technology platforms, where all stakeholders gather in defining their national goals and priorities for innovation (Stuip et al., 2004). These national technology platforms (NTP) will organize themselves in an international network and represent a strong voice for cooperation towards a common European research policy.



The ECTP is aimed at taking the sector to a “new and better high level” by identifying and analyzing the major challenges in terms of sustainability, security, competitiveness, etc., and by developing strategies for how to address these challenges in the coming decades, in order to fulfill the society’s needs (Rodriguez, 2004).

The ECTP-organization involves many actors, stakeholders and shareholders: contractors, manufacturers, representatives of the European Commission and of the EU-member states, designers, users, consumers, financial entities, service providers, research centers, education centers, cities and regions. It consists of a High Level Steering Group (HLG), a Support Group (SG) and Secretariat, Focus Areas, National Platforms and a Plenary Assembly. The organization is supported by a Term of Reference (TOR) and the main products are a European Vision 2030 and the corresponding Strategic Research Agenda (SRA). Six Focus areas have been defined, four of them are object-related and two methodological.

[5] Participants are: Japan (GRI, Osake; Kyoto Univ.), China (Tongji Univ.; Hohay Institute), Taiwan (Chen-Kung Univ.), Korea (Pusan Univ.), Thailand (Chulalongkorn Univ.)



A tentative Vision 2030 and corresponding breakthroughs have been defined by the participating members in the different Focus Areas. By January 2005 the following framework had been formulated:

FOCUS AREA	*VISION 2030*
CITIES AND BUILDINGS	CITIES ARE DESIRABLE TO LIVE IN
UNDERGROUND CONSTRUCTION	INFRASTRUCTURES SAFELY UNDERGROUND
NETWORKS	A GUARANTEE FOR BETTER LIVING AND WORKING
CULTURAL HERITAGE	BUILT PAST FOSTERED IN FUTURE
QUALITY OF LIFE	BUILT SUSTAINABLE FOR MAN AND NATURE
MATERIALS	MULTI-FUNCTIONAL SUSTAINABLE AND NO-IMPACT

FOCUS AREA	*MAJOR BREAKTHROUGH*
CITIES AND BUILDINGS	ENERGY OPTIMISED, CHANGES ANTICIPATED
UNDERGROUND CONSTRUCTION	ROBOTISED, COST EFFICIENT, NO IMPACT
NETWORKS	INTEGRATED DESIGN, MANAGEMENT, OPERATION
CULTURAL HERITAGE	INTERNATIONALLY ACCEPTED REGULATIONS
QUALITY OF LIFE	SAFE, HEALTHY BUILDINGS, HAZARD-CONTROLLED
MATERIALS	SYNTHESIS AT ALL SCALES AND PROCESSES

In this context ELGIP published its geotechnical message, and agreed that it will participate in the various Focus Areas and National Technology Platforms, supported by their corresponding national RTD programs. ELGIP's message is:

1. Geotechnical engineering is the application of the science of soil and rock mechanics, engineering geology and other related disciplines to civil engineering design and construction, and to the preservation and enhancement of the environment. Geo-engineering plays a key role in civil engineering projects, since the built environment is based on or in the ground.

2. Soil is a natural material, which cannot easily be quality controlled. Because of complexities of soil behavior and natural variations the corresponding uncertainties have restricted the profession traditionally to largely empirical solutions. At present, the state-of-the-art in the geotechnical profession adopts on many occasions a factor of 50% to account for unforeseen circumstances.

3. Societal and economic losses from natural hazards, such as floods, landslides, earthquakes, cyclones and waste disposals, are underestimated, awareness of associated risks and cost is insufficient, and mitigation and regulation to avoid damage and loss of life is inadequate.

4. The engineering challenge for the coming years is to establish, by a clear explanation of the risks and cost to society, the role and value of geotechnics in the reduction of effects of hazards and technical failures and the delivery of economic constructions, and thus improve sustainability and safety while supporting a high quality of life. There is a great innovative potential in geotechnics.

This has led to an active involvement in one of the ECTP sub themes of Focus Area Quality of Life, i.e. Mitigating Natural and Technical Hazards, related to soils and construction that affect and threatens humans, property and the natural and built environment. Technical hazards considered are blasts, impacts, fires, and terrorist attack. Earthquakes, slides, floods, windstorms, coastal erosion and land subsidence are common natural hazards, either sudden, moderate or slow, and they affect and disrupt society and the built and natural environment by loss of life, disruption to agriculture, loss of housing, evacuation, economic loss, contamination and loss of health. The trend shows an increasing impact due to growing population in vulnerable areas and increasing intensity due to expected climate changes. The potential damage and socio-economic loss is tremendous.

Milestones

	Objectives	Breakthrough
2010	Eliminate the uncertainty and the unpredictability	Developing fundamental understanding of natural and geological processes.
	Innovation - Knowledge of hazards and their distribution and probability. - Knowledge of related assets and their distribution and condition. - Development of innovative sensor technologies for monitoring functioning of soils and constructions under natural hazards. - New techniques for analysis (including mathematical models), mapping, monitoring and early detection of natural hazards	
2020	Achieve timely and appropriate holistic solutions	Implementing solid, sustainable and economic solutions and remedial measures. Creating emergency preparedness and awareness in the society.
	Innovation - Common approach to mitigation and risk management. - Developing new cost-effective practical methods for preventing or mitigation of natural hazards. - Research on social behavior in potential risk areas – living with risks – and methods for increasing the awareness. - Novel ground treatment remediation methods to mitigate effects of natural hazards. - Validation of new analysis techniques and new sensor systems to monitor performance and safety of infrastructure.	
2030	Natural hazards are quantified and managed in a safe and reliable manner at a European level	Integration and co-ordination of interdisciplinary expertise, actively including end-users and policy-makers. Dissemination by education and training. Maintaining of preparedness and awareness
	Innovation - Proven advances in predictability and insurability of natural hazards. - Establish a strong framework to enable exchange of information and knowledge. - Training program for young research scientists and continuing education program for promotion and dissemination of gained excellence - Operational alert systems for natural hazards all over Europe.	

The challenge for the construction sector is to respond to this trend in an efficient, sustainable and economic manner. To assess and mitigate the risk due to these hazards and to ensure optimum solutions, there is an urgent need to encourage multi-disciplinarity in an applied science approach and in hazard-vulnerability assessment. Since hazards do not respect national boundaries, coordinated and collaborative research is required at European level to eliminate the uncertainty, the unpredictability and the consequences of hazards and to achieve timely and appropriate holistic solutions so that disruption by natural hazards becomes marginal and acceptable.

The vision is: by 2030 the impact of hazards on the stability of soils, foundations and civil engineering works will be quantified and managed in a safe and reliable manner at a European level. The built environment should be safe from technical hazards. Milestones, breakthroughs and innovations are shown in the table above. The next step is to find acceptance for this view in the ECTP and then research and technology development projects can be defined according to the given scope, which may more easily find a place in international and regional R&D strategies and support from research funds.

5 CHALLENGES

There are plenty of opportunities and challenges for innovation in soil mechanics and geotechnical engineering. A real potential is in micro-geomechanics, where sophisticated modern tools open insight into the complexity of the small world. New concepts are required to accommodate constitutive behavior and mechanical modeling at micro levels. Bio- and chemo-technology will allow for new types of extensive ground improvement techniques. Most topics include collective and pluriform processes and require a multi-disciplinary approach and a joint effort in creating awareness of the benefits, since realization needs solid support from experts, industry and end users. Some examples follow.

5.1 *Joining with bio- and nanotechnology*

In *Nature* (May 1996) James Ferris and in *Science* (November 2003) Jack Szostak reported that clay particles, in particular montmorilonite in combination with other minerals (aluminium- and boriumsilicates), stimulate the formation of membranes and the construction of small RNA-chains. This supports the idea that life may have developed from dead materials in encapsulate RNA-soup near pre-historic submarine hydrothermal vents. Research in this field focuses on amphiphilic molecules (at one side hydrophilic and the other side hydropobic), which form the cell membranes of life forms today. The importance for the geotechnical profession is that in this research, insight in microscopic behavior and the construction of sophisticated microscopic equipment and observation methods are being developed which will be useful for the insight and understanding of microscopic mechanical behavior of clays.

Another striking recent advancement in this field is the potential of applying bio- and chemotechnology for the improvement of soil mechanical properties, such as in the concept Smartsoils®, launched by GeoDelft in 2004, a realization of "Soil on Demand", the vision that in future soils in situ will be treated at nano- and micro level to meet specific performance criteria, while using sustainable, natural and user-friendly processes.

SmartSoils® offers promising opportunities for real innovation in the world of geotechnics. In the last 25 years, we have become increasingly aware of how our lifestyles affect the environment. Increased population density brings increased industrial activity, an increased demand for infrastructure and housing, more waste and higher demands on the existing land space. All of these factors point to the need for a new perspective on how we can best use our available land areas and consider what options exist to adapt the land to responsibly meet our needs. In some cases, there is also potential to recycle waste materials and turn them into new construction materials.

SmartSoils® are technologies that can direct the localization and rate of natural soil processes that influence soil properties. By influencing these processes, there is real potential to alter the properties of the soil (for example, permeability and stiffness) in relatively short time. Thus, by means of bio- and nanotechnologies, we can generate soil to suit a desired purpose, such as changing the natural soil to make it suitable as a foundation for construction. Some examples follow:

- Self-cleaning Road: a unique road construction for transformation and remediation of contaminated dredged material over the life time of the road;
- BioSealing: a natural biological process for self-detection and sealing of seepage in water impermeable barriers;
- BioGrout: in-situ cementation of permeable soils for strength improvement with retention of permeability;
- Black Clay: active carbon/clay organic barrier for isolating material from the environment;
- Drillmix: Fluid for horizontal directional drilling that is suitable for use in salt-water;
- ETAC: Two-component grout system with an adaptable hardening time for efficient tunnel boring, even in impermeable soils.

The challenge is to extend SmartSoils® to organic clay, peat, and contaminated and uncontaminated dredged sludge.

5.2 *Micro-mechanical behavior observed*

The micro-mechanical behavior of soil, in particular organic soils, is not well understood. Interpretation of field behavior using common principles of soil mechanics, such as Terzaghi's effective stress principle, may appear improper. Micro-mechanical behavior has to be formulated, involving special microscopic tests and the development of specific micro-macro mechanical models. Understanding the micro characteristics makes drastic changes in the behavior and sustainability at macro-scale possible (Porro, 2004). This has been proven for other granular media, like concrete, so why not for soils?

Cheng (2004) investigated the mechanical behavior of organic soil on the micro- and nanolevel. One of the challenging puzzles in soil mechanics is strain localization. The real physico-chemical mechanism occurs on a micro-level (µm-scale). New laboratory techniques, involving simple triaxial testing at micro-scale (ESEM), providing correct vapor conditions and pressure levels, has recently become possible and this introduces not only sophisticated techniques and a close interaction with geochemistry and geology, but also a major effort to investigate the great variety of constitutional behavior at micro level (Fig.37). A special microscopic tensile-compression module has been developed to perform simple triaxial testing, and permitting the observation of the response of different components. The fabric of microstructures and microfossils has been found to play a central role. The results have been validated using DEM (Discrete Elements Modeling) applied to composites with fibers in various orientation and content (Fig.36).

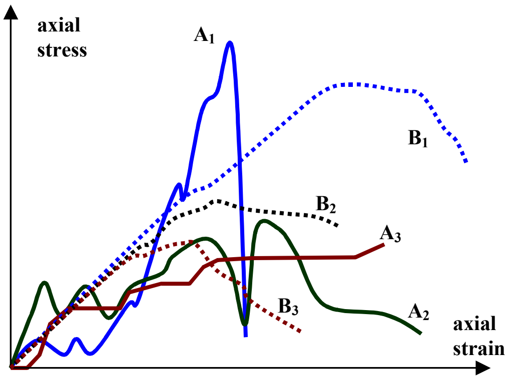


Figure 36. Bold lines: microscopic tests (ESEM): natural clay (A_1), inorganic clay (A_2), and remolded clay (A_3); dotted lines: DEM analysis of various fibre contents, 75% (B_1), 55% (B_2), and 45% (**B_3**).

The macro mechanical behavior, expressed in terms of cohesion and friction, is shown to be composed of the development of micro-cracks and buckling of micro-structures. It seems that the concept of Coulomb, i.e. friction of soil particles, does not apply for organic soils and we may conclude that our understanding of cohesion and friction as we imagine it in sands or inorganic clays may be false for other types of soil.

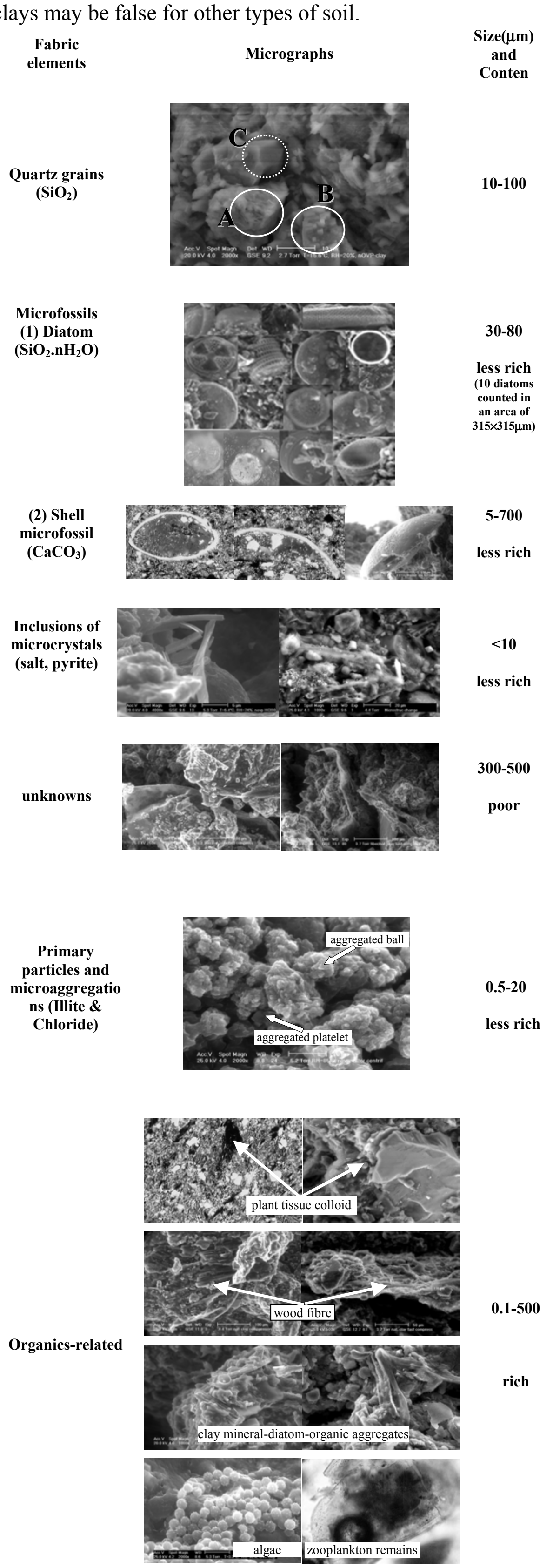


Figure 37. Atlas of organic OVP clay (Cheng, 2004)

Knowledge of microstructure behavior is indispensable to bring our insight in the mechanical behavior of soils a firm step forward. It provides a basis to modify soft soils using advanced bio- and chemotechnology.

5.3 *Multi-scale modeling*

As an example of the involvement of different microscopic processes, a micro-macro mechanical model suitable for reed peat is presented, as a theoretical approach. The details are presented in Annex I.

It is well known that for compressible matrix particles Terzaghi's effective stress principle does not hold. The empirical stress strain relation $d\varepsilon = -\alpha d\sigma'$ may hold, but the common definition of σ' (intergranular stress) needs to be extended. A new interpretation is required based on a micro-mechanical model that incorporates internal equilibrium between the pore fluid and the matrix and accommodates the matrix particles' compressibility.

Assume a matrix, a part of which contains particles being hollow stalks filled with water, with a thin, relatively weak and less pervious skin, like long balloons (Fig.38). In fact, the soil consists of a double porosity model, an external system of interconnected pores and an internal system of isolated pores. The density change of the matrix is then related to the internal water, of similar constitution as the pore fluid. Since equilibrium requires the internal pressure to be equal to the external (the only separation is the flexible skin of the stalks) the storage equation becomes (see Annex I)

$$(k/\mu)\, \nabla \bullet \nabla p = \nabla \bullet v + v \bullet \beta \nabla p + \beta\, \partial p/\partial t$$

Here, the free pore fluid flow is related to the external pore system, but the storage is related to both systems. Hence, the interpretation of porosity must be considered with care. When, for such a system, all the water is removed and the remaining solid material is considered alone then a porosity value is found of almost equal to 100%. This value does not coincide with properties of the flow system of the external pore water.

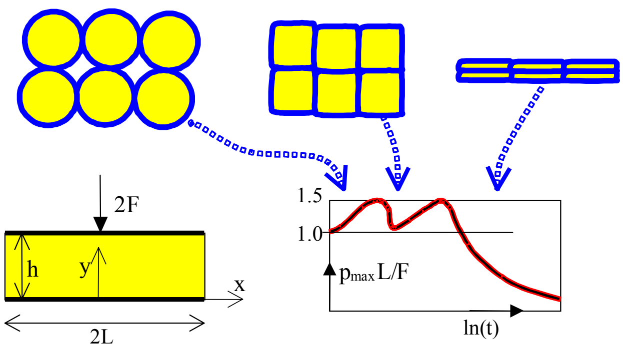


Figure 38. Three stages in a squeeze test on saturated reed peat

Assume the reed stalks round (2-dimensional), long and placed randomly in a horizontal formations, then squeezing makes them into squares when the external pore space has disappeared (stage I). This process is controlled by the external pore fluid dissipation and the corresponding total equilibrium. Next, the internal pore water system will dissipate. Water inside the stalks passes through the stalk skins (stage II), which has anticipating extra resistance (lower permeability). Finally, the remaining pore water is dispelled (stage III), and only then will effective stresses develop (Fig.38).

Horizontal deformation is more or less prevented, since the stalks react as reinforcement in horizontal planes. Given the structure, a closed form solution can be found for the squeeze test. Such a situation corresponds to a vertical-drains consolidation system. Consider the right half of the test: $0 < x < L$ (Fig.38). Interpretation of $\nabla \bullet v$ gives

$$\nabla \bullet v = v_{,y} = \varepsilon_{y,t} = gF$$

It is uniform in x and proportional to the total load F, since the intrinsic process is viscous flow. Here, g is to be determined from the equilibrium condition

$$F = L \, {}_0\!\int^L p dx \qquad \text{valid at all time}$$

When the pore fluid compressibility β is not zero, an initial uniform pressure distribution occurs at the very beginning of the loading, with an immediate strain according to

$$\varepsilon = -\beta F/L$$

Next, the pressure distribution changes under $\varepsilon_{y,t}$ which is uniform in x, towards a parabolic form with a maximum at $x = 0$ (see below). This behavior is like the Mandle effect (Mandle, 1953).

Stage I. The convective effects are active only vertically, not influencing the horizontal process; thus: $v \bullet \beta \nabla p = 0$. The solution for a jump loading at $t = 0$ is found using Laplace transformation techniques (see Annex I). To find the real behavior of p at time $t = 0$ and time $t = \infty$, the Laplace transform limits and Taylor series are applied. For small time the pressure at $x = 0$ becomes

$$p_{max} \, (t = 0^+) = F/L$$

and for large time

$$p_{max} \, (t = \infty) = 3F/2L$$

This result shows that the maximum pore pressure at $x = 0$ immediately after a sudden loading F is equal to F/L and then with time it develops to $3F/2L$. This transient period to reach the final value (99%) is (see Annex I)

$$t_{99\%} = 2L^2 \beta \gamma / K$$

where γ is the specific volumetric weight of water and K the hydraulic permeability of the external pore system. For a specific (permeable peat and pore water with 1% gas): $L = 1m$, $\beta = 10^{-5} m^2/N$, $\gamma = 10^4 N/m^3$ and $K = 10^{-4}$ m/s, the 99% transient period for stage I becomes $2000\ s = 0.56\ hr$.

Stage II: when the water in the external pore system is squeezed out the internal system (water in the stalks) becomes activated. Dissipation requires more time, since the water has to percolate through the skin of the stalks. The same formulation applies as for Stage I. The pressure distribution may first adopt a uniform pressure distribution before dissipation creates a parabolic pressure distribution with a maximum finally equal to $3F/2L$. The time to reach this is inversely proportional to the ratio of permeabilities of the external and internal pore system. If the internal system permeability is $K = 10^{-5} m/s$, then the 99% transient period for Stage II is calculated as $5.6\ hr$.

Stage III: after dissipation of the internal pore water a familiar consolidation process occurs where the particle's compressibility (the folded stalk skins) plays a role and the principle of effective stress can be adopted. Then, the pore pressure decays as function of the increase in effective stress. For the example, the 99% consolidation period may take longer because permeability and the compressibility have decreased. If $\alpha = 10^{-6} m^2/N$, $K = 10^{-8} m/s$ then $c = 10^{-6} m^2/s$ and, following Terzaghi, the 99% hydrodynamic period becomes $T_{99\%} = L^2/2c = 5.78\ days$.

The three stages may result in a peculiar behavior of pore pressure, effective stress and vertical settlement (Fig.39). While the pore pressure fluctuates locally at higher level than the loading and settlements occur at high rate from the beginning, one may speculate about effective stresses of plasticity. The example shows that this might not be the proper approach.

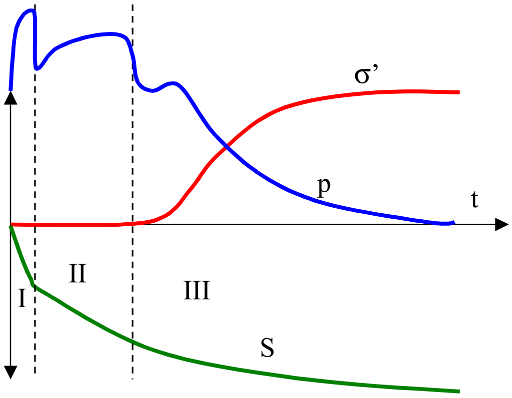


Figure 39. Theoretical developments of pore pressure (p), settlement (S) and effective stress (σ') in a squeeze test on peaty soil, in three stages

Since peat is composed of various systems of pore structures including sand and clay and process parameters are usually not constant, measurements may not easily provide a clear distinction of the different processes. The study of micro-mechanics is an interesting challenge, and significant advancement may be expected, if we are able to influence some of the microscopic processes. For the understanding we need to develop and validate adequate microscopic models.

5.4 *Visualizing the unseen together*

In many cases on-site soil investigation is poor and the real subsoil condition remain unseen, which can sometimes lead to risky situations. It is up to the geotechnical engineer to create proper awareness about such circumstances and to suggest and design adequate monitoring and alertness procedures. The expert was traditionally on the site in early times, but nowadays he is more likely to be remote from the site or not involved at all. We should bring the expert back to site: the remote observational specialist. Some examples follow.

5.4.1 *Safeguarding Pisa's tower*

An outstanding example of visualizing the unseen is the stabilization of the bell tower of Pisa, a difficult challenge to civil engineering. It required sophisticated simulations and trials, and careful continuous monitoring and control under strict requirements to preserve the artistic and historic value of this monument (Burland et al., 2002). It also required high-level expertise in many aspects, particularly during the guidance of restoration works. In a previous Terzaghi Oration, Jamiolkowski (2002) highlighted the details of this successful and unique achievement made possible by high scientific knowledge and a great variety of multidisciplinary skills. The restoration was completed in June 2001.

5.4.2 *Controlling complex tunneling by on-line monitoring*

In the busy shopping centre of The Hague an underground tram station and car parking has been built. The construction consists of two diaphragm walls to a depth of 28 m in mainly sandy soils, a covering roof and internal floors, vertically anchored. Inflow of groundwater during construction was restricted by a jet grout arch (a strut for the diaphragm walls and support against uplift) in some places and a silicate gel layer formed by permeating grouting on other places. Unfortunately, scour from under the arch (sand boils) and local collapse caused a delay of the works. After two years – devoted to judicial disputes more that technical discussions – construction was resumed in 2000 using excess air pressure of 1.14 bar (11m pressure height) in the underground building pit, which imposed difficult labor conditions. A heavier floor, additional ballast and anchors were applied to guarantee stability against uplift. Soon it appeared that the dewatering system above the silicate gel layer did not work properly: serious well clogging was occurring. Heave and subsequent excessive deformation of the walls could jeopardize the entire project.

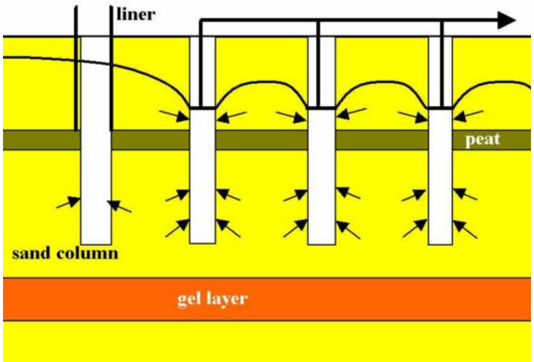


Figure 40. Drainage system, tram-tunnel construction, The Hague

The contractor decided to ask for specialist advice from geotechnicians, geobiologists and geohydrologists. They discovered that due to the long delay gel material had caused a locally high PH (Luger et al., 2003). This dissolved organic matter locally that precipitated near the well filters, where the PH was normal. The unusual clogging problem was solved by applying smart instrumented sand columns and a temporary isolation system (PVC-liner) making full profit of a thin semi-pervious peat layer (Fig.40). About 100 piezometers were installed and the records every 10min were directly processed and sent to a database, that facilitated directs access to all parties involved: client, contractor, consultant, local authority and insurance company. Easy visualization by colored maps indicated normal, alert and critical levels, in the last case automatically sending emails and SMSs. This ‘dynamic’ warning system comprised permanent “virtual” specialist’s eye on site and provided the proper conditions to complete the construction safely in 2004.

5.4.3 *Lower safety margins shorten construction time*

The Betuwe route, a double track freight railway of 160 km connecting Rotterdam harbor with Germany, is being constructed at 4.5 billion euro and will be completed in 2010. The embankment of this railway leads into the western part of the Netherlands through an area of extremely soft soils. In particular, consolidation time and residual settlements composed a serious risk to the progress of the project. The high risk profile of the Sliedrecht-Gorinchem section of the Betuwe line, characterized by peat soil, a high water table, a short construction time, various subsidence-sensitive objects in the direct proximity and inflexible links with existing infrastructure (Fig.41), formed the start of the formation of the public-private partnership ‘Waardse Alliantie’, a new type of alliance between the contractor and the client (Molendijk et al., 2003). Together they took on the challenge to redesign and build this section within the tight time schedule and the appointed budget. Both parties agreed to share the costs of identified risks including unexpected soil conditions and possible damage to existing infrastructures.

The alliance provided a unique opportunity to optimize the design, to maintain a constant watch on the unseen and to act swiftly to compensate for any unexpected situation. The risk on excessive settlement and instability was controlled by on-line monitoring, a well-structured data management system and various fall back scenarios, which allowed for smaller safety margins, a continuous adjustment of extrapolated predictions of the consolidation process and residual settlements, and – most important – a significant shorter construction period. The alliance started in 1999 and completed its task successfully on time, in November 2003, and it achieved a reduction of about 10% of the original project cost. The major part of the success of the project had its origin in a sound risk management strategy for covering the geotechnical aspects. This benefit was shared amongst all the parties involved.

Figure 41. The new Betuwe line runs close to existing infrastructure; by applying a monitoring concept to the largest risk factor: the subsidence, a new type of PPP contract could be established, leading to significant cost reduction and an excellent project result.

5.5 *Collective consciousness*

Information from our senses goes to our brains. The senses (organs) work in a systematical way. They do their job in a repetitive manner. However, our brains both receive and give outputs selectively. This selection is based on our consciousness, the “Mind”. Mind is often divided into two parts, rational and emotional. The rational part is more similar to a computer. It gathers and processes information and knowledge. It solves problems and makes logical decisions based on received information. The emotional part is more complex to explain. In it feelings and many other impressions and associations are created and stored. It controls our social behavior, our moods and personality.

Collective consciousness enables a group of living beings to perform activities or share experiences as if being just one organism. It seems that the more advanced a species is, in terms of evolution, the less collective consciousness there is, and the more self-consciousness arises.

Collective consciousness is not noticed or thought about until one is separated from it. In separation one is more likely to develop unusual hobbies and activities. The more isolated one is from the masses, the more isolated one is from their rules and customs. The more separated from collective consciousness, the more open-minded and accepting of unorthodox and revolutionary ideas, wondering the purpose of existence and looking for it outside everyday reality, a true basis for innovation. The result of this quest eventually can be rewarding.

For a real breakthrough separation is necessary, and for the acceptance of breakthrough, collectiveness is required. This paradox finds its root in our brains where rational and emotional parts of mind control our individual behavior. The challenge is to “collect” multiple brains, both in rational as well as in emotional sense, by forming a selective collective consciousness with a focus on sharing. An application of this concept in geotechnics is GeoBrain, where rational methods and expertise meet intuitional feelings and experience.

5.6 *Collective brains: GeoBrain*

The initiation of large-scale infrastructure projects and subsequently, their design and construction is becoming more and more complex. Policies concerning multi-functional space require sustainable building, and the integral approach to projects, procedures and licenses, existing cables and pipelines, pollution and archeology emphasize that in general the subsoil represents the greatest risk in construction and maintenance. Such a situation calls for quick and comprehensive answers adopting all available expertise and experience, presented in a clear and understandable manner.

GeoBrain, one of the seven Geo-concepts of GeoDelft, provides a new toolbox for the integral approach of complex situations where the subsoil is an important risk, which can provide an objective view on the consequences of choices. This development has a strong parallel with some other disciplines, such as the medical science where with diagnostic systems empirical knowledge is being translated into generally applicable concepts. Today's ICT makes this approach possible. GeoBrain can therefore close the gap between theory and practice (Hemmen, 2004). It is aimed directly at reducing uncertainty and the costs of failure, thereby increasing the quality of the profession and minimizing the risk in geo-engineering works. GeoBrain forms a unique facility, an "intelligent" tool complementary to common physical and numerical facilities. By artificial intelligence, using neural networks that create new relations between the various knowledge sources and by coupling of numerical prediction models and physical tests with the complete set of data interpretations, predictions and practical experiences, expert views and test results can be translated into objective information. The latest presentation techniques are used for the information transfer.

The gap stems from the fact that there has been, hitherto no possibility of systematic learning from case histories of completed projects. Practicing engineers have, from time to time, proposed ad-hoc rules and equations based on experience and field observations but no unified framework for experience dissemination is available till now. In recent years, the development of computational intelligence tools such as fuzzy logic and artificial neural networks etc. make it possible for engineers to analyze field or 'monitored' data of construction and truly apply 'observational' methods as recommended by various codes of practice. Up to now geotechnical institutes and engineers have concentrated on the development of computational prediction models to simulate the observations of engineering practice, sometimes with limited success. GeoBrain aims at bringing the vast experience of various aspects of foundation construction together and make it available to design and practicing engineers in the form of readily usable tools, which can close the gap between theory and practice.

The general objectives of GeoBrain are to discover white spots in knowledge and focus collective research, decrease risk in construction projects and reduce losses, improve the image of contractors and geo-engineers, improve working conditions, ensure completion of these projects without unforeseen delays and last but not least to reduce insurance fees. Insuring work or projects is especially hard in foundation engineering and the drilling technology. The fees for a policy are very high and most of the times the policy does not cover major failures.

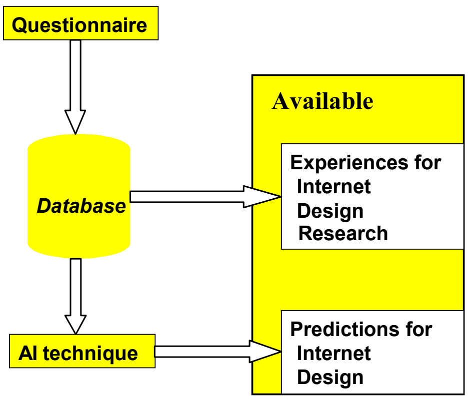


Figure 42. GeoBrain structure

GeoBrain is addressing these problems directly by developing an experience database from case histories and disseminating these experiences via the Internet. This database, complemented with expert knowledge, can be used to make predictions with an Artificial Intelligence (AI) based methodology. There are therefore two kinds of output from the total GeoBrain system: experiences and predictions (Fig.42).

Hemmen defines experience in its context and describes how it can be captured objectively using obligatory questionnaires, which have been composed together with the users and providers (based on a dropdown list). Predictions are made using Bayesian Belief Networks, built from expert knowledge and validated by real case experiences. The Internet is the ideal medium to display the experiences and the results of a prediction. Assigned users can search by type of work or via a map of the location. Afterwards queries can be refined. The predictions can be made on the same website.

A first pilot for the design of sheet piling was made in 2002 with designers and contractors where the latest knowledge of design and practical experience was focused on the economics of a project. Based on the collected experiences the evidence of failure to surrounding utilities and foundation elements was found in at least 40% of all cases. GeoBrain has the potential to make a real difference in geo-engineering by helping the designers to use experience. Future plans for GeoBrain are to widen the topics and to internationalize its use. Participating members in a GeoBrain project gain short term advantage, which leads to a dynamic market and better quality.

CONCLUSIONS AND REMARKS

Chapter 1 dealt with advancing insight. Various examples illustrate aspects of geotechnical uncertainties and limitations, from which we make the following statements:

- From uncertain soil behavior to controlled and sustainable performance, we are still a long way from delivering soil 'on demand'.
- The risks to society from the growing numbers living in vulnerable areas susceptible to hazards (climate change, landslides, earthquakes, floods, storms) are leading to demands for increased public awareness, control by early warning systems and smart mitigation measures.
- Valuable experiences from practice are not rigorously studied nor generally disseminated or available, and they evaporate with time.
- Our way of rational thinking and analysis is deductive. Hence, our understanding is fragmented. Reality is all encompassing. Its simulation requires comprehensive and multi-scale integration.
- Innovation requires dedicated and active multi-disciplinary working.
- The effects of subjective individual interpretation of facts and data are underestimated.
- The transparency of information (the "google" effect) and user-friendly sophisticated computer models invite quasi-science and virtual (in)competence, with disregard for the increasing complexity of many field problems. They also reduce investment in research. How can we guarantee reliability in geotechnical works?
- Transparency of the uncertainty in geotechnical works will facilitate proper risk assessment and risk sharing by use of appropriate forms of contracts, avoiding inflexibility, indecision and time overrun.
- We must explain to decision makers the uncertainty in geotechnics and raise awareness of the social and economic benefits that derive from risk reduction.

Chapter 2 dealt with characteristics of knowledge. We looked at knowledge in all its aspects, and we can draw the following conclusions:

- The ability to handle massive information will become the key to survival.
- Knowledge management and ICT are the new drivers for the economy.
- The three modes of knowledge, i.e. facts, experience and wisdom, (will) lead to three types of ICT-concepts: Dbases, Ebases and Vbases, the last one related to values. In these concepts transparency, collectivity and sustainability of skills can be realized.
- The route towards progress takes place in successive steps, through sensing and thinking in the technological innovation cycle and through vision and concept in the societal innovation cycle, where decisions are made.
- Knowledge without quality has no value. Quality is however subjective. What counts is the success factor.

Chapter 3 dealt with communication. Various forms of communication were discussed and analyzed, from which we can conclude that:

- Dissemination of knowledge is crucial to our existence. Education and training are a permanent part of life and they deserve continuous attention.
- Communication takes place in many forms and it involves providers and receivers, at equal or unequal level. Hence, for ICT to be supporting all forms of communication, it should accommodate these different situations.
- In communication the questions “Is it possible?” (technological innovation cycle) and “Is it acceptable?” (societal innovation cycle) are highly relevant. Geotechnical engineers should develop skills to address the second question.
- Communication outside the technical world is becoming essential. We must inform others of soil-related uncertainties and how to deal with them.

Chapter 4 dealt with contextualization:

- Science and technology have penetrated to the hearts of economy, politics and culture, and they create new uncertainties and risks. Solutions to these problems can only be found through science and technology.
- Beside accuracy, objectivity and truth, social and practical robustness is also required, and to participate in this context researchers have to speak out.
- To win attention for value we add we must use the proper language, and make a better and more coherent use of the powerful role the media play in the societal decision process.
- There are great opportunities for the geotechnical profession, but we must get involved and raise our profile.

Finally, Chapter 5 dealt with challenges. I gave illustrations of promising innovations, such as the introduction of biotechnology and multi-scaling (micro-geotechnics), the creation of collective brains in geotechnics, and a risk-sharing contract model. The geotechnical profession, though being highly empirical, provides so many opportunities and chances. There is a great added value to sell.

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ANNEX I A MECHANICAL MODEL FOR REED PEAT

The general conservation principle states

$$\nabla \bullet (gw) + \partial g/\partial t = 0 \qquad (1)$$

Here, w is the absolute velocity and g an intrinsic mass-related property. Applying (1) to a pore fluid

$$\nabla \bullet (n\rho w) + \partial (n\rho)/\partial t = 0$$

Here, n is the actual porosity and ρ the fluid density. Introduction of the specific discharge (matrix-relative pore-fluid velocity: $q=n(w-v)$ gives

$$\nabla \bullet (\rho q) + \nabla \bullet (n\rho v) + \partial (n\rho)/\partial t = 0$$

Here, v is the absolute matrix velocity. Elaboration yields

$$\nabla \bullet (\rho q) + n\rho \nabla \bullet v + v \bullet \nabla (n\rho) + \partial (n\rho)/\partial t = 0$$

$$\nabla \bullet (\rho q) + n\rho \nabla \bullet v + D(n\rho)/Dt = 0$$

$$\nabla \bullet (\rho q) + n\rho \nabla \bullet v + nD(\rho)/Dt + \rho D(n)/Dt = 0 \qquad (2)$$

Here, $D(\ )/Dt$ is the matrix substantial derivative. Applying (1) to the matrix yields

$$\nabla \bullet ((1-n)\rho' v) + \partial ((1-n)\rho')/\partial t = 0$$

Here, ρ' is the matrix (particle) density. Elaboration yields

$$(1-n)\rho' \nabla \bullet v + v \bullet \nabla ((1-n)\rho') + \partial ((1-n)\rho')/\partial t = 0$$

$$(1-n)\rho' \nabla \bullet v + D((1-n)\rho')/Dt = 0$$

$$(1-n)\rho' \nabla \bullet v + (1-n)D(\rho')/Dt = \rho' D(n)/Dt \qquad (3)$$

Inserting (3) into (2) gives

$$\nabla \bullet (\rho q) + \rho \nabla \bullet v + nD(\rho)/Dt + (\rho/\rho')(1-n)D(\rho')/Dt = 0 \qquad (4)$$

Using Darcy's Law: $q = -(k/\mu)\nabla p$ with p the pore pressure, k the intrinsic permeability (only related to the pore geometry in m^2), and $\mu = \rho\eta$ the dynamic viscosity, η the kinematic viscosity, dependent on temperature and slightly on pressure, (4) becomes

$$\nabla \bullet ((k/\eta)\nabla p) = \rho \nabla \bullet v + nD(\rho)/Dt + (\rho/\rho')(1-n)D(\rho')/Dt$$

For (k/η) constant in space and time this becomes

$$(k/\mu)\nabla \bullet \nabla p = \nabla \bullet v + nD(\rho)/\rho Dt + (1-n)D(\rho')/\rho' Dt$$

Expressing the pore fluid density change as function of p, according to (independent of space and time) $\beta = d(\rho)/\rho dp$ gives

$$(k/\mu)\nabla \bullet \nabla p = \nabla \bullet v + n\beta Dp/Dt + (1-n)D(\rho')/\rho' Dt \qquad (5)$$

For the matrix the principle of conservation of mass gives ρV is a constant. Here, V is a control volume. Thus, also V^{-1} is an intrinsic property. Applying (1) gives

$$\nabla \bullet (v/V) + \partial (1/V)/\partial t = 0$$

$$(1/V)\nabla \bullet v + D(1/V)/Dt = 0$$

$(1/V)\,\nabla\bullet v = (1/V^2)D(V)/Dt$

$$\nabla\bullet v = D(V)/VDt = D\varepsilon/Dt \quad (6)$$

Here, ε is the volume strain. Inserting (6) into (5) gives

$$(k/\mu)\,\nabla\bullet\nabla p = D\varepsilon/Dt + n\beta Dp/Dt + (1-n)D(\rho')/\rho' Dt \quad (7)$$

The first three terms correspond to the common storage equation, assuming the matrix particles incompressible. The last term represents the effect of particle compressibility. Next, ε and ρ' have to be expressed in terms of p. This involves the interactive mechanical behavior of the matrix particles themselves. The common approach is using Terzaghi's effective stress principle: $\sigma = \sigma' + p$. It holds for incompressible matrix particles. An empirical relation between ε and σ' is: $d\varepsilon = -\alpha d\sigma'$, independent of p. Then (7) becomes

$$(k/\mu)\,\nabla\bullet\nabla p = -\alpha D\sigma'/Dt + n\beta Dp/Dt$$

$$(k/\mu)\,\nabla\bullet\nabla p = -\alpha D\sigma/Dt + (\alpha+n\beta)Dp/Dt$$

For a constant loading σ and small strains the common consolidation equation is found

$$c\,\nabla^2 p = \partial p/\partial t \quad \text{with} \quad c = (k/\mu)/(\alpha+n\beta) \quad (8)$$

It can be solved in terms of p for various boundary and initial conditions.

Now, returning to the situation of compressible matrix particles. Assume a matrix a part of which contains particles being hollow stalks filled with water, with a thin and weak and less pervious skin, like long balloons. In fact, the soil consists of a double porosity model, one external system of interconnected pores and one internal system of isolated pores. The density change of the matrix is related to the inside water (of similar constitution as the pore fluid). So, (5) applies and since equilibrium requires the internal pressure to be equal to the external (the separation is the flexible skin of the stalks) the storage equation becomes

$$(k/\mu)\,\nabla\bullet\nabla p = \nabla\bullet v + n\beta Dp/Dt + (1-n)\beta Dp/Dt$$

$$(k/\mu)\,\nabla\bullet\nabla p = \nabla\bullet v + \beta Dp/Dt \quad (9)$$

Assume the stalks being round (2-dimensional), long and placed in a horizontal formation, then squeezing makes them finally squares when the external pore space has disappeared. So, the volume around one particular stalk could change is from $4r^2$ to πr^2. This process is controlled by the external pore fluid dissipation and the corresponding total equilibrium, in fact a boundary value problem. Next, the internal pore water system will dissipate, passing through the stalk skins. Finally, the remaining pore water is dispelled while effective stresses will develop

A solution can be found for a squeeze test based on (9). Such a situation corresponds to a vertical-drains consolidation system. The field equation is for this situation (see main text)

$$(k/\mu)p_{,xx} = gF + \beta p_{,t}$$

or

$$p_{,xx} = \chi F + \lambda p_{,t} \quad \text{with} \quad \chi = g\mu/k \quad \text{and} \quad \lambda = \beta\mu/k \quad (10)$$

Laplace transform of (10) is, assuming F is a jump loading at $t = 0$

$$\mathbf{p}_{,xx} = \boldsymbol{\chi} F/s + \lambda s\mathbf{p} - \lambda p(0^+) \quad (11)$$

Here, $\mathbf{p}$ and $\boldsymbol{\chi}$ (in bold) are the Laplace transforms

$$\mathbf{p} = {}_0\!\int^\infty p\, e^{-st}dt \quad and \quad \boldsymbol{\chi} = {}_0\!\int^\infty \chi\, e^{-st}dt$$

The initial pressure $p(0^+) = F/L$ is uniform in x, since any non-uniform distribution of p requires flow for which requires time. The particular solution of (11) is

$$\boldsymbol{\chi} F/s + \lambda s\mathbf{p}_1 - \lambda F/L = 0$$

$$\mathbf{p}_1 = (F/\lambda s)(\lambda/L - \boldsymbol{\chi}/s) = (F/sL)(1-\boldsymbol{\xi}) \quad \text{with} \quad \boldsymbol{\xi} = \boldsymbol{\chi} L/s\lambda$$

The homogeneous solution of (11) becomes

$$\mathbf{p}_2 = A_1 exp(x\sqrt{(s\lambda)}) + A_2 exp(-x\sqrt{(s\lambda)})$$

The total solution is $\mathbf{p} = \mathbf{p}_1 + \mathbf{p}_2$

$$\mathbf{p} = (F/sL)(1-\boldsymbol{\xi}) + A_1\, exp(x\sqrt{(s\lambda)}) + A_2\, exp(-x\sqrt{(s\lambda)}) \quad (12)$$

Boundary conditions are

$$\mathbf{p}_{,x}/_{x=0} = 0 \quad \text{and} \quad \mathbf{p}/_{x=L} = 0$$

from which A_1 and A_2 are determined

$$A_1 = A_2 = -(1/2)(F/sL)(1-\boldsymbol{\xi})/cosh(L\sqrt{(s\lambda)})$$

Hence, (12) becomes

$$\mathbf{p} = (F/sL)(1-\boldsymbol{\xi})(1-cosh(x\sqrt{(s\lambda)})/cosh(L\sqrt{(s\lambda)})) \quad (13)$$

Next, equilibrium condition provides the expression of $\boldsymbol{\xi}$. Elaboration gives

$$F/s = {}_0\!\int^L \mathbf{p}dx =$$

$$= (F/sL)(1-\boldsymbol{\xi})\, {}_0\!\int^L (1-cosh(x\sqrt{(s\lambda)})/cosh(L\sqrt{(s\lambda)}))\, dx =$$

$$= (F/s)(1-\boldsymbol{\xi})\,(1- tanh(L\sqrt{(s\lambda)})/(L\sqrt{(s\lambda)}))$$

Hence, with $\boldsymbol{\zeta} = L\sqrt{(s\lambda)}$

$$\boldsymbol{\xi} = 1 - (1- tanh(\boldsymbol{\zeta})/\boldsymbol{\zeta})^{-1} \quad (14)$$

Inserting this value in (13) gives

$$\mathbf{p} = (F/sL)(1- tanh(\boldsymbol{\zeta})/\boldsymbol{\zeta})^{-1})(1-cosh(x\sqrt{(s\lambda)})/cosh(\boldsymbol{\zeta})$$

The maximum pressure is found at $x = 0$,

$$\mathbf{p}_{max} = (F/sL)(cosh(\boldsymbol{\zeta}) - 1)/(cosh(\boldsymbol{\zeta}) - sinh(\boldsymbol{\zeta})/\boldsymbol{\zeta}) \quad (15)$$

To find the real behaviour of p at time $t = 0$ and time $t = \infty$, the Laplace transform limits are applied to (15). For small time

$$p_{max}(t=0^+) = s\mathbf{p}_{max}(s=\infty) = (F/L)(1- 1/\boldsymbol{\zeta})(1- 1/cosh(\boldsymbol{\zeta}) = F/L$$

and for large time, using Taylor series

$$p_{max}(t=\infty) = s\mathbf{p}_{max}(s=0^+) = (F/L)(cosh(\boldsymbol{\zeta}) - 1)/(cosh(\boldsymbol{\zeta}) - sinh(\boldsymbol{\zeta})/\boldsymbol{\zeta}) =$$

$$(F/L)(1 + \boldsymbol{\zeta}^2/2! + \boldsymbol{\zeta}^4/4! - 1)/(1 + \boldsymbol{\zeta}^2/2! + \boldsymbol{\zeta}^4/4! - (\boldsymbol{\zeta} + \boldsymbol{\zeta}^3/3! + \boldsymbol{\zeta}^5/5!)/\boldsymbol{\zeta}) =$$

$$(F/L)(\boldsymbol{\zeta}^2/2 + \boldsymbol{\zeta}^4/24)/(\boldsymbol{\zeta}^2/3 + \boldsymbol{\zeta}^4/6) = (3F/2L)(1 - 5\boldsymbol{\zeta}^2/12) = 3F/2L$$

The result of the limits in time is that the maximum pore pressure at $x = 0$ immediately after a sudden loading F is equal to F/L and then with time it develops to $3F/2L$.

The Laplace inverse transform of p_{max} can be found by the Direct Method (Shapery, 1961)[6] or by the Improved Direct Method (Barends,

[6] Shapery, R.A. 1961. Approximation methods of transform inversion for visco-elastic stress analysis. Proc. IVth US National Congress of Appl Mech, p:1073-1085.

1999)[7]. The results is shown in Figure A.1 as function of u, where $u = t/L^2\lambda$ and related to s by $s = exp(-1.4u)/(uL^2\lambda)$ for IDM and $s = 1/2u$ for DM. The 99% line shows a transient period[8] of about $0 < u < 1.5$.

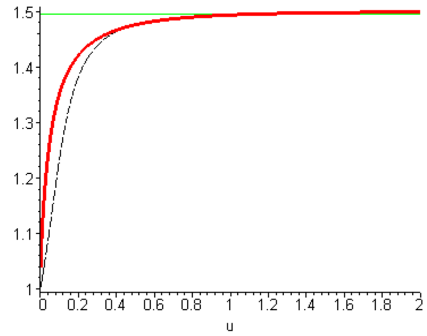

Figure A.1. The development of p_{max} by IDM and DM (dotted)

From the Taylor series expansion the period to reach the final value (within 99%) is at $(1 - 5\zeta^2/12) = 0.99$ or $s_{99\%} = 0.024(L^2\lambda)^{-1}$. The relation between s and t is given by the IDM-method, which states for this situation (2D plane symmetry) $s = exp(-1.4t(L^2\lambda)^{-1})/t$. Elaboration for $s_{99\%}$ gives

$$t_{99\%} = 2.15L^2\lambda \approx 2L^2\beta\gamma/K \qquad (16)$$

To find the velocity and corresponding settlement (14) is elaborated. From (10) we find

$$\mathbf{g} = (k/\mu)\boldsymbol{\eta} = (k/\mu)(\lambda/L)\boldsymbol{\xi} = (k/\mu)(\beta\mu/kL)\boldsymbol{\xi} =$$

$$(\beta/L)(1 - (1- tanh(\zeta)/\zeta)^{-1}) = (\beta/L)/(1- \zeta coth(\zeta))$$

The Laplace transform of the velocity of the top plate is given by

$$\mathbf{v}_{top} = {}_0\!\int^h \nabla\bullet \mathbf{v}\, dy = {}_0\!\int^h \mathbf{g}F = \mathbf{g}hF$$

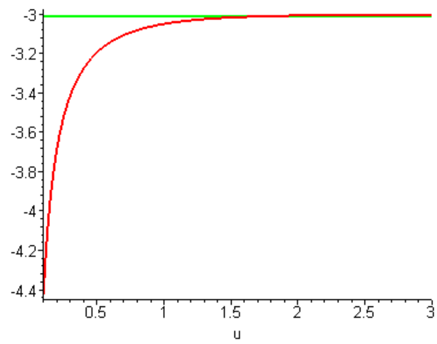

Figure A.2 The velocity of the top plate and the 99% value.

The real velocity is expressed with $u = t/L^2\lambda = tk/(\beta\mu L^2) = tK/(\beta\gamma L^2)$ and IDM the result is

$$v_{top} = s\mathbf{v}_{top} = s\mathbf{g}hF = (hF/L^2\lambda)(\beta/L)s/(1- \zeta coth(\zeta)) =$$

$$hFK/(\gamma L^3)\ \zeta^2/(1-\zeta coth(\zeta)) \quad \text{with} \quad \zeta = \sqrt{(exp(1.4u)/u)}$$

And shown in Figure A.2, $v_{top}(\gamma L^3/hFK)$ as function of u (time).

The velocity is initially infinite, and after a transient period it becomes a constant $v_{top} = -3hFK/(\gamma L^3)$, which can be easily shown by Taylor series expansion. The transient period is about $0 < t < 2\beta\gamma L^2/K$, in accordance with (16). For $\beta = 0$ (incompressible pore water) the transient period becomes infinitely small. The corresponding settlement S of the top plate becomes $S = {}_0\!\int^t v_{top}\, dt$. The result found by integration is shown in Figure A.3, $S(L/h\beta F)$ as functionof u.

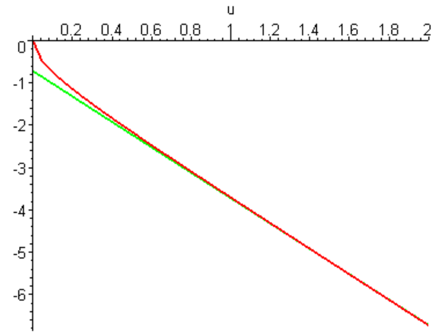

Figure A.3 The settlement of the top plate, exact and asymptotic

The settlement becomes steady after a transient period of about $0 < t < \beta\gamma L^2/K$, which is shorter than found for the velocity (reduction due to integration). Regression analysis shows for the settlement

$$S(L/h\beta F) = 0.72 + 3u \quad \text{or} \quad S = 0.72(h\beta F/L) + 3t(hFK/\gamma L^3)$$

For $\beta = 0$ the initial part disappears. The settlement will continue until the external pore space has vanished (all the free water is squeezed out). In the case of equal cylindrical stalks the process stops when

$$S_{max}L = Nr^2(4-\pi) = 0.86\ Nr^2 = 0.86\ hL/4 = 0.22\ hL \quad \text{or} \quad S_{max} = 0.22h.$$

Here, N is the number of stalks and r the radius. For a specific situation (permeable peat and water with 1% gas): $h = 0.5m$, $L = 1m$, $\beta = 10^{-5}\ m^2/N$, $\gamma = 10^4\ N/m^3$, $K = 10^{-4}\ m/s$, and $F/L = 2\ 10^4\ Pa$ the following is found

Transient period velocity	$t = 2\beta\gamma L^2/K = 2000sec = 0.56\ hr$
Transient period settelement	$t = \beta\gamma L^2/K = 1000sec = 0.28\ hr$
Steady velocity	$v_{top} = 3hKF/(\gamma L^3) = 3\ 10^{-5} m/sec$
Steady settlement	$S = 0.072 + 3\ 10^{-5} t\ m$
Maximum settlement	$S_{max} = 0.11m$
All water squeezed out	$t = 1266\ sec = 0.35\ hr$

In this case at time $t = 0.35\ hr$ or $u = 1.266$ the maximum pressure of $3F/2L = 3\ 10^4\ Pa$ at $x = 0$ has been almost established.

[7] Barends F.B.J. 1999. *IDM for transient problems*. Proceedings of XII ECSMGE 99: Geotechnical Eng for Transportation Infrastructure, Balkema Rotterdam, p:659-665

[8] A similar type of transient period has been reported for an oedometer test at constant rate of strain: Wissa, A.E.Z., Christian, J.T., Davis, E.H. and Heiberg, S. 1971. Consolidation at constant rate fo strain. J. Soil Mech & Found. Div, ASCE, Vol 97, SM10, p:1393-1413.